Thirty Years Reporting on NASA's Earth Science Program

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Editor's Corner

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The coming of autumn has yielded a harvest of NASA Earth Science activity for us to report on, with missions at all stages of their life cycle–some coming to an end, some still going strong, some in development.

After 11 successful years, the joint NASA–CNES Ocean Surface Topography Mission (OSTM), or Jason-2, stopped collecting science data on October 1, 2019, due to aging-related issues. Final decommissioning operations were completed on October 10. Following in the footsteps of the Ocean Topography Experiment (TOPEX)/Poseidon and Jason-1, Jason-2 measured sea level from space with an accuracy of just a few centimeters, covering the global ocean once every 10 days (example sea surface height anomaly map below). Designed to last 3 years with an expected lifetime of 5 years, the satellite provided data for more than 2000 scientific papers during its 11-year lifespan. It also overlapped with Jason-3, launched in 2016, which will continue measuring global sea level through 2020. Two future Jason-Continuity of Service (CS) satellites are planned for launch in 2020 and 2025.[1] Together, these satellites have charted the steady rise of global sea levels—see graph below. Because global sea level rise is one of the most sensitive indicators of climate change, as well as one of the largest impacts on society, these satellites form a lynchpin of climate change research.

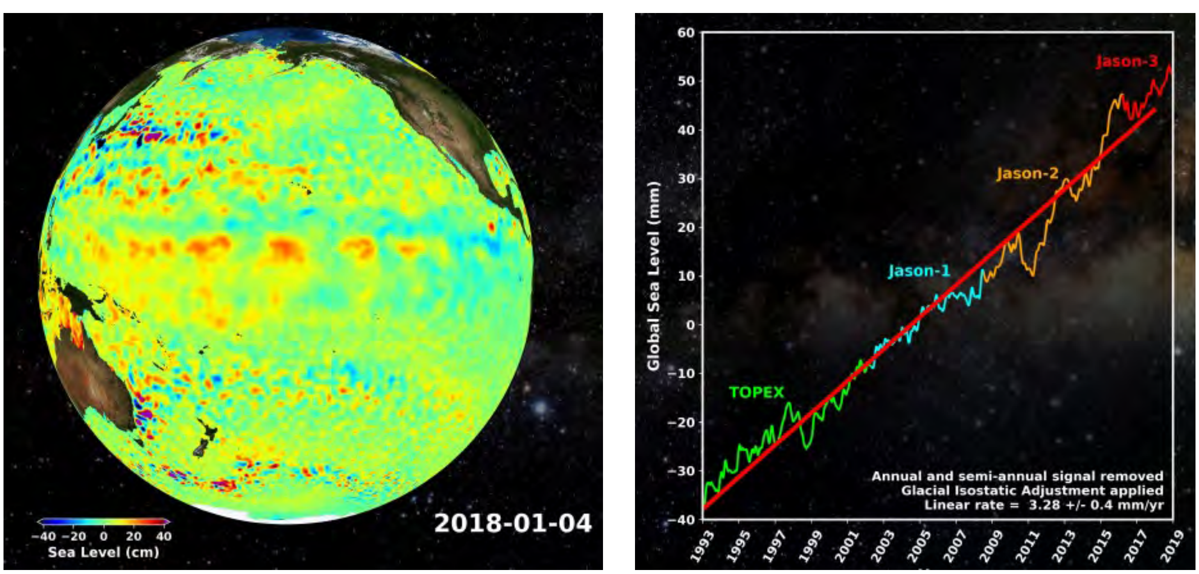
After a period of cross-calibration with Jason-3, and a few months in an adjacent orbit that improved the effective resolution of the sea level observations from both satellites, Jason-2 was moved to a new orbit to protect Jason-3 and eventually Jason-CS (which will occupy the same orbit as Jason-3).[2] Congratulations to all those involved in Jason-2, past and present, for the outstanding success of the mission.

As planned, the Total Solar Irradiance Calibration Transfer Experiment (TCTE) science mission ended on June 30, 2019, after collecting more than 5 years of total solar irradiance (TSI) data. The TCTE instrument was built and delivered in five months from program start,

[1] These will launch as the European Copernicus Sentinel-6A and -6B missions.

[2] Learn more about the end of Jason-2's mission at *https://www.nasa.gov/press-release/ocean-monitoring-satellite-mission-ends-after-11-successful-years*.

continued on page 2



On October 1, 2019, the joint NASA–CNES Ocean Surface Topography Mission (OSTM), or Jason-2, stopped collecting science data. The image [*left*] shows areas in the Pacific Ocean where sea levels were lower (blues) or higher (reds) than normal during the first week of January 2018. Jason-2 contributed to a long-term record of sea surface height measurements that has been used to chart the steady rise of sea level since the early 1990s. The graph [*right*], which combines data from the Ocean Surface Topography Experiment (TOPEX)/Poseidon, Jason-1, Jason-2, and Jason-3 satellites, shows global sea level measurements over a 26-year period. **Image credit:** NASA/JPL

In This Issue

Reminder: To view newsletter images in color, visit *eospso.nasa.gov/earth-observer-archive.*

and served as a bridge between the Solar Radiation and Climate Experiment (SORCE) and the Total and Spectral Solar Irradiance Sensor 1 (TSIS-1).[3] TCTE flew onboard the U.S. Air Force's Space Test Program Satellite-3 (STPSat-3), which was initially an 18-month technology-demonstration mission. However, NOAA extended the TCTE mission multiple times to provide the desired TSI-measurement overlap. NASA assumed responsibility for continued STPSat-3 TCTE operations in 2017. LASP performed the instrument operations and data processing. TCTE met its primary mission requirement to ensure continuity of the now 4-decade long TSI climate data record and confirmed the TSI value of 1361 W/m^2.

Meanwhile, NASA Headquarters (HQ) decided to extend SORCE operations into January 2020. Launched in 2003, SORCE had battery issues for years, though scientists and engineers successfully managed to work around the power limitations. However, SORCE began to experience communication outages in April 2019, prompting NASA HQ to consider accelerating the SORCE decommissioning plan. The SORCE Key Decision Point-F (KDP-F)[4] meeting was held in July to evaluate the decommissioning plan, schedule, and budget for mission close-out, and to decide between a mid-July 2019 passivation (turn-off) or the original January 2020 passivation date.

The final decision to continue SORCE operations until January 15, 2020 was based on SORCE's compelling science. Phase F will start the day after passivation and continue through September 2020 to produce and archive the final data products, capping off an outstanding 17-year mission.

In the meantime, TSIS-1 continues to produce high quality solar irradiance data from the International Space Station. TSIS is currently midway through the second year of its five-year prime mission. Preparations for TSIS-2 have already begun, with a launch-readiness date of February 2023.

With regard to the future, the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission passed its KDP-C review in August 2019. PACE now enters its critical design phase. The Critical Design Review (CDR) of the Ocean Color Instrument (OCI)—the primary instrument on PACE—is scheduled for December 2019, with a mission-level CDR in February 2020.

PACE represents NASA's next advance in the combined study of Earth's ocean-atmosphere–land system. Currently scheduled for launch in December 2022, PACE will study *phytoplankton*—microscopic algae that form the base of the aquatic food chain—as well as clouds and atmospheric aerosols.

[3] In order to fill a potential gap in the 35+ year TSI climate record after the failed launch of the Glory mission in 2011 and to address the growing concerns regarding SORCE's ability to continue operations due to battery degradation, the TCTE TIM instrument was quickly readied for flight by refurbishing the SORCE ground-based Total Irradiance Monitor (TIM) witness unit.

[4] KDP–F marks the entry into Phase F, the final stage in a NASA mission's life cycle.

OCI is a hyperspectral scanning radiometer that will measure reflected light from the near-ultraviolet through near-infrared, coupled with a multiband filter spectrograph to extend coverage into the shortwave infrared. The instrument is being built at GSFC. Unlike previous Earth-observing instruments used for ocean color science, OCI's spectral coverage will allow it to identify both beneficial and harmful (potentially toxic) phytoplankton communities.

PACE will also carry two multiangle polarimeters dedicated to aerosol and cloud science. Polarimeters measure the ways that particles (and molecules) change the orientation of light waves interacting with them, providing unique information on particle composition and size. The Spectropolarimeter for Planetary Exploration (SPEXone) will be built and overseen by the SRON Netherlands Institute for Space Research and Airbus Defence and Space Netherlands. The Hyper-Angular Rainbow Polarimeter (HARP2) will be built by the Earth and Space Institute at the University of Maryland, Baltimore County (UMBC). The synergy across OCI and the two polarimeters will enable significant advancements in coupled ocean–atmospheric science. Both SPEXone and HARP2 passed their critical design reviews in February 2019 and April 2019, respectively.

Congratulations to the PACE team on clearing the KDP-C milestone. Learn more about PACE at *https://pace.gsfc.nasa.gov*.

NASA selected the Geosynchronous Littoral Imaging and Monitoring Radiometer (GLIMR) instrument for development under NASA's fifth Earth Venture Instrument (EVI-5)[5] solicitation. GLIMR will be a hyperspectral ocean color radiometer that will measure reflected sunlight from optically complex coastal waters in narrow wavebands, leading to unique observations of ocean biology, chemistry, and ecology in the Gulf of Mexico, portions of the southeastern U.S. coastline, and the Amazon River plume—where the Amazon River enters the Atlantic Ocean. The PI for GLIMR is **Joseph Salisbury** from the University of New Hampshire (UNH).

Raytheon Aerospace will build GLIMR, which will be integrated on a NASA-selected platform. The current plan calls for launch in the 2026–2027 timeframe into a geosynchronous orbit where it will be able to monitor a wide area, centered on the Gulf of Mexico. From this vantage point, GLIMR will be able to gather many observations of a given area each day—a critical capability in studying phenomena such as the lifecycle of coastal phytoplankton blooms and oil spills in a way that would not be possible from a satellite in low-Earth orbit. The unique spatial and temporal resolution of GLIMR will make its data highly complementary to those from other low-Earth orbit satellites that observe the ocean (e.g., PACE).

Congratulations to Salisbury and the GLIMR team on being chosen as EVI-5.[6]

In this issue, we report on NASA's Southern Hemisphere ADditional OZonesondes (SHADOZ) project. SHADOZ has collected ozone profile measurements for more than 20 years using balloon-borne *ozonesondes*. The regularly coordinated launches are from different locations in the tropics and subtropics (25° N to 25° S latitude). When SHADOZ was conceived back in 1997, observations in this latitude range were nearly nonexistent. With the backing of NASA HQ, GSFC and NOAA's Climate Modeling and Diagnostic Laboratory (now known as the Global Monitoring Division) proposed the network as a way to remedy the lack of balloon-based ozone data for a number of (at that time) upcoming NASA and international ozone-monitoring instruments.

SHADOZ collected its first official data in 1998. The observations have led to scores of published scientific discoveries by a user community numbering in the hundreds, and with an impact extending far beyond the original SHADOZ objectives. I extend my congratulations to principal investigator **Anne Thompson** [GSFC] and the entire SHADOZ team on two decades of successful ozonesonde launches. Turn to page 4 of this issue to learn more about the history, scientific discoveries, and technical achievements of SHADOZ.

On July 18-20, 2019, the Smithsonian's National Air and Space Museum hosted a celebration on the National Mall in Washington, DC, of the 50th anniversary of the Apollo 11 Moon landing. NASA participated and had numerous tents set up with a variety of exhibits and hands-on activities. NASA's Science Mission Directorate and Science Support Office (SSO) assisted the NASA Headquarters Office of Communications in planning and staffing the event. While most of the activities focused on the Moon, NASA's Earth and Planetary Science programs were also prominently featured. For a summary of the Earth-related activities at the Apollo 50th anniversary event, please turn to the summary article on page 16 of this issue. ■

[5] GLIMR was chosen from among eight proposals considered under the EVI-5 solicitation. The Earth Venture program contributes small, targeted science investigations complementing NASA's larger Earth-observing satellite missions. There are three categories of investigation: Mission (EVM), Instrument (EVI), and Sub-Orbital (EVS). To learn more, visit *https://essp.nasa.gov/projects*.

[6] To learn more about GLIMR, see *https://www.nasa.gov/press-release/nasa-targets-coastal-ecosystems-with-new-space-sensor*.

See page 55 for a list of undefined acronyms used in the editorial and table of contents.

SHADOZ at 20 Years: Achievements of a Strategic Ozonesonde Network

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Introduction

Twenty years ago, *The Earth Observer* published an article announcing the start of the Southern Hemisphere ADditional OZonesondes (SHADOZ) project—*https://tropo.gsfc.nasa.gov/shadoz*. It began as a two-year initiative to collect measurements of ozone throughout the atmosphere, or *ozone profiles*, using balloon-borne *ozonesondes* by coordinating regular launches at 10 stations in the tropics and subtropics.[1] Ozonesonde data have long been recognized as important resources for satellite algorithms and validation—see *What Is an Ozonesonde?* on page 5. However, when the SHADOZ network was proposed by NASA's Goddard Space Flight Center (GSFC) and the National Oceanic and Atmospheric Administration (NOAA)'s Global Monitoring Division (GMD)[2] in 1997, regular soundings at latitudes between 25° N and 25° S were nearly nonexistent. NASA Headquarters supported the plan to remedy a lack of balloon-based ozone data for the upcoming Ozone Monitoring Instrument (OMI) and Microwave Limb Sounder (MLS) on NASA's Earth Observing System (EOS) Aura platform (launched in 2004), the SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY (SCIAMACHY) on the European Space Agency's Envisat satellite (launched in 2002, and ending in 2012), and the ongoing series of ozone instruments on the NOAA and NASA joint polar-orbiting satellites and their European counterparts.

When the SHADOZ network was proposed by NASA's Goddard Space Flight Center and NOAA's Global Monitoring Division in 1997, regular soundings at latitudes between 25° N and 25° S were nearly nonexistent.

SHADOZ collected its first official ozone profiles in 1998. Since then, SHADOZ data have led to scores of published scientific discoveries by a user community numbering in the hundreds. The network reached its 20-year milestone in 2018, thus providing a fitting opportunity to reflect on its scientific contributions. This article begins with some history and background on SHADOZ, including details on the network and the ozonesonde instrument itself. It then discusses several spinoffs and major scientific and technological advances resulting from SHADOZ.

SHADOZ History and Background

From its inception, the principal goal of the SHADOZ ozonesonde network was to develop a better ozone profile climatology for satellite algorithm development. Compared to mid- and polar latitudes, where dozens of sounding stations had operated since the 1960s, the tropics were undersampled. In 1997, only Natal, Brazil (5.8° S, 35.2° W) had a continuous sounding record for more than 20 years, and there were few soundings over tropical Africa or Asia. However, at least ten stations had operated in the tropics and subtropics during short-term field investigations, or *campaigns*: e.g., NASA's Transport and Atmospheric Chemistry Experiment-Atlantic (TRACE-A), in 1992; and Pacific Exploratory Mission (PEM)-Tropics-A, in 1996.[3] Sondes operating in

[1] To learn more, see "SHADOZ (Southern Hemisphere ADditional OZonesondes): A New Ozone Dataset for the Earth Science Community" in the July–August 1999 issue of *The Earth Observer* [**Volume 11**, **Issue 4**, pp. 27-30—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/July_Aug99.pdf#page=27*].

[2] At the time SHADOZ was proposed, the GMD was known as the Climate Monitoring and Diagnostics Laboratory.

[3] The National Academy of Sciences issued a study report on the need for a Global Tropospheric Chemistry Program (GTCP) in 1984. NASA's response was the Tropospheric Chemistry Program, which has funded field investigations from the mid-1980s up to the present. The 1983–2001 field studies operated under the umbrella of the Global Tropospheric Experiment (GTE) project. All the investigations listed here were part of GTE. These investigations collected a comprehensive set of atmospheric chemical observations. Learn more at *https://www-gte.larc.nasa.gov/gte_hmpg.htm#table*.

these campaigns were valued as complements to aircraft measurements by providing day-to-day data from fixed sites, as well as profiles above maximum flight altitudes. Thus, the infrastructure to resume soundings (including the facilities, launch gas, and personnel) was already in place, which provided additional impetus for NASA to create SHADOZ. At that time, the lead author of this article, **Anne Thompson** [GSFC], was named principal investigator (PI) for the project, a position she still occupies today.

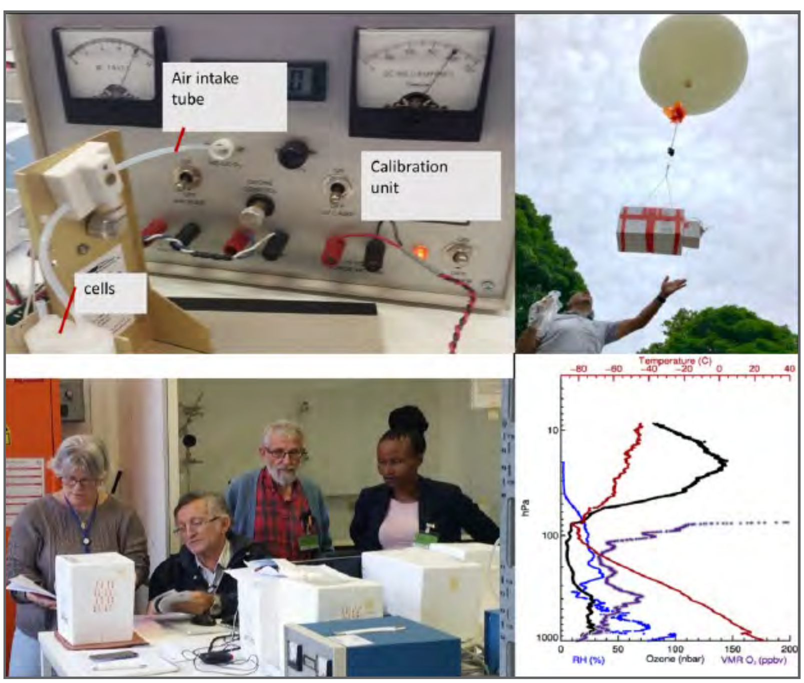
What Is an Ozonesonde?

An ozonesonde is a small instrument that when affixed to a modified *radiosonde* and a weather balloon [*upper right photo below*] measures ozone (O_3) *partial pressure** as the package rises through the troposphere and stratosphere. With a 1200- or 1500-g (~2.6- or 3.3-lb) balloon, burst typically occurs between 5-10 hPa (or 5-10 mb), commonly found at an altitude of 30-35 km (~19-22 mi). Ozone and pressure-temperature-humidity (PTU) data are returned to the ground via telemetry during a two-hour ascent and descent cycle, after which the instruments are usually lost. Ozone is measured via an *in situ* technique where ambient air is pumped into two inert cells containing dilute potassium iodide (KI) solutions. The reaction generates an electric current, the strength of which is proportional to the amount of ozone present. The effective vertical resolution of the ozone data is 50-150 m (~164-492 ft)—which is much better than that of optical remote sensing instruments deployed on satellites. Furthermore, sondes are virtually all-weather instruments; the *electrochemical method* (which is the method used for all SHADOZ ozonesonde launches) is not affected by clouds and precipitation, as many spectroscopic techniques are.

The ozone profile shown below [*bottom right*] was obtained over Ascension Island (7.97° S, 14.4° W) Measurements are in partial pressure and mixing ratio units and are shown along with pressure and temperature profiles from the radiosonde that accompanies the ozonesonde. The radiosonde also measures wind speed and direction. Column-integrated ozone amounts in *Dobson Units*** are used for comparisons to readings from satellites and ground-based spectrometers. Typical total column ozone (TCO) over the tropics is 250-325 DU.

* In a mixture of gases, the partial pressure is the amount of pressure each gas would exert if it were the only gas in the volume.

**The Dobson unit (DU) is a measurement of the total amount of ozone in the atmosphere above a point on the earth's surface. One Dobson unit is equivalent to a layer of pure ozone 0.01 mm thick at standard temperature and pressure. The unit is named after Gordon Dobson, who in the 1920s built the first instrument to measure ozone from the ground. While primarily used for atmospheric ozone measurements, some other satellite measurements do use DUs, e.g., column nitrogen dioxide (NO_2) from OMI and TROPOMI.



Shown here are photos of: the anatomy of an ozonesonde and its calibrator [*upper left*]; two ozonesondes in their packages with a radiosonde attached, prior to launch via balloon [*upper right*]; and a photo [*lower left*] that shows SHADOZ operators from Brazil and South Africa (front) with two coaches from NASA's Wallops Flight Facility (background) during a training exercise for the Jülich Ozonesonde Intercomparison Experiments, or JOSIE (discussed later in the main text). The graph [*lower right*] shows an ozone profile [black curve] obtained over Ascension Island as it appears on the SHADOZ website; it is described in the text. Note that this profile also shows temperature, humidity, and pressure [red, blue, and purple curves respectively]. **Image credits**: *Upper and lower left photos*—Anne Thompson [GSFC]; *upper right photo*—Patrick Cullis [GMD]; *graph*—SHADOZ

When SHADOZ began, there were 10 contributing stations that were well distributed across the Southern Hemisphere—hence the name.

The SHADOZ network design concept was (and continues to be) intended to:

- Supply existing stations with additional sonde expendables (~$1000/launch) to achieve a frequency of 2-4 launches per month;
- collect all sonde data from a given station;
- provide training for conducting sonde launches;
- select stations to cover the entire tropical zone; and
- partner with tropical entities (e.g., meteorological services, space agencies, universities) and sponsors (e.g., NASA, NOAA, Japanese and European agencies) to leverage resources with a goal of sustaining operation, long term.

Implementation

When SHADOZ began, there were 10 contributing stations that were well distributed across the Southern Hemisphere—hence the name. In 1999 the Dutch Koninklijk Nederlands Meteorologisch Instituut (KNMI) [Royal Dutch Meteorological Institute], a partner in Aura's OMI instrument, added Paramaribo, Suriname (5.81° N, 55.21° W) and a Japanese–Malaysian Meteorological Department partnership began sending data from Kuala Lumpur, Malaysia (2.73° N, 101.7° E). In 2005–2006 Hanoi, Vietnam and Hilo, HI, in the north, and Irene, South Africa and La Réunion Island (France), in the south joined, bringing the total number of stations sending data to the SHADOZ archive to 16. The 14 stations with at least 10 years of operation are shown in **Figure 1**, and coordinates, sponsoring organizations, and numbers of ozone profiles available as of early 2019 are listed in the **Table** on page 7. Four stations are located in the subtropics: Hanoi and Hilo in the north, and Irene and Réunion in the south—see Figure 1 for locations. Of additional value for satellite calibration is the presence of ground-based, total-column ozone instruments [e.g., Brewer spectrophotometer, Dobson spectrophotometer, Système D'Analyse par Observations Zénithales (SAOZ) spectrometer], either nearby or collocated at 10 of the SHADOZ stations.

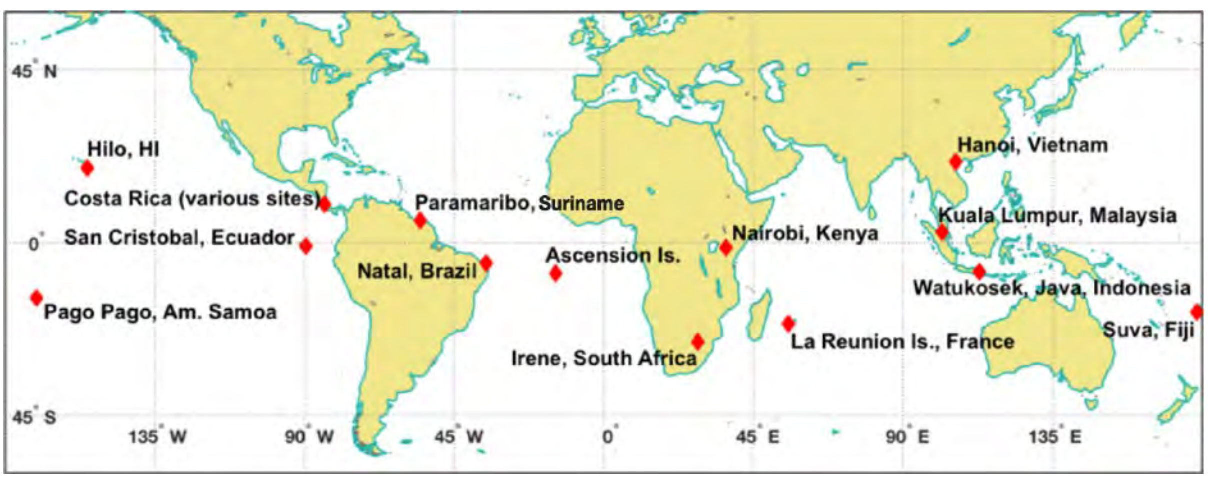


Figure 1. Map of SHADOZ stations from which more than 10 years of continuous data have been obtained during the time SHADOZ has been operational (1998–2019). Coordinates, periods of operation, and total profile numbers for each station are listed in the Table on page 7. **Image credit**: Debra Kollonige

Outreach and Communications

Two key positions in the SHADOZ organization are the SHADOZ PI and SHADOZ Archiver[4] both based at GSFC. They keep in touch with many SHADOZ co-investigators around the world, and with the larger scientific community through a variety of methods: Online communication via email and other social media are used for day-to-day exchange of information, and SHADOZ issues one or two newsletters each year (published on the website) to keep readers up to date on the project's activities.

[4] The SHADOZ Archiver is responsible for collecting sonde data from the station partners, posting the data to the website, and transmitting SHADOZ profiles to the World Ozone and Ultraviolet Data Centre (WOUDC).

Table. List of SHADOZ stations that have compiled at least 10 years of data.

Station [latitude, longitude]	Partner Organization	Years Operational	Number of O_3 Profiles Obtained*
Pago Pago, American Samoa [14.3° S, 170.71° W]	American Samoa Observatory (NOAA/GMD)	1998–2019	752
Hilo, HI, U.S. [19.72° N, 155.05° W]	Mauna Loa Observatory (NOAA/GMD)	1998–2019	1054
San Cristóbal, Galapagos, Ecuador [0.9° S, 89.6° W]	Instituto Nacional de Meteorologia e Hidrologia [National Meteorological and Hydrological Institute of Ecuador]	1998–2008; 2012–2016	442
San Pedro, Costa Rica [10° N, 84° W]	University of Costa Rica (at several locations)	2005–2019	605
Paramaribo, Suriname [5.81° N, 55.21° W]	Meteorological Service of Suriname and KNMI	1999–2018	748
Ascension Island [7.97° S, 14.4° W]	U.S. Air Force and GSFC	1998–2010; 2016–2019	710
Natal, Brazil [5.8° S, 35.2° W]	Instituto Nacional de Pesquisas Espaciais (INPE) [Brazilian Space Agency], GSFC, and NASA's Wallops Flight Facility	1998–2011; 2013–2018	653
Irene, South Africa [25.9° S, 28.22° E]	South African Weather Service	1998–2008; 2012–2019	374
Nairobi, Kenya [1.3° S, 36.76° E]	Kenyan Meteorological Department and Méteoswiss	1998–2019	905
La Réunion, France [20.89° S, 55.48° E]	Université de la Réunion, Météo-France, and Centre National de la Recherche Scientifique (CNRS)	1998–2018	647
Kuala Lumpur, Malaysia [2.73° N, 101.7° E]	Malaysian Meteorological Department	1998–2010; 2012–2018	427
Hanoi, Vietnam [21.02° N, 105.8° E]	Vietnam Meteorological and Hydrological Administration and Japan Agency for Marine-Earth Science and Technology (JAMSTEC)	2004–2018	268
Watukosek, Java, Indonesia [7.57° S, 112.65° E]	Lembaga Penerbangan dan Antariksa Nasional (LAPAN) [Indonesian Institute of Aeronautics and Space]	1998–2013	343
Suva, Fiji [18.15° S, 178.4° E]	University of the South Pacific (NOAA/GMD)	1998–2019	437

*These numbers represent number of profiles from each station as of February 2019.

Another important opportunity for information exchange among SHADOZ investigators is through interactions with colleagues at workshops, major scientific meetings, conferences, and assemblies. In particular, SHADOZ team members regularly participate in activities related to the World Meteorological Organization/Global Atmospheric Watch (WMO/GAW), the Network for the Detection of Atmospheric Composition Change (NDACC),[5] the Stratosphere-Troposphere Processes and their Role in Climate (SPARC) project, the International Ozone Commission (IO3C), and the triennial Ozone Research Managers Meetings held at WMO Headquarters in Geneva.

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Data Disposition

Data transmission frequencies from an individual station to the SHADOZ network vary, from transmittal immediately post-launch to two-to-four times annually. Data processing is carried out by station or sponsor personnel and checked by the

[5] To learn more about NDACC, see "The Network for the Detection of Atmospheric Composition Change: 25 Years Old and Going Strong" in the September–October 2016 issue of *The Earth Observer* [**Volume 28**, **Issue 5**, pp. 4-15—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Sept-October%202016%20color%20508.pdf#page=4*].

SHADOZ Archiver. With a 20-year record, the SHADOZ sustainability goal has exceeded expectations: Currently, more than 8000 ozone and PTU profile sets are available through the GSFC website (provided earlier) and secondary archives, which include the World Ozone and Ultraviolet Data Centre (WOUDC), NDACC, and the Aura Validation Data Center (AVDC) at GSFC. The new Copernicus Atmospheric Monitoring System (CAMS) in Europe is ingesting many satellite datasets in near-real time, creating secondary products (e.g., assimilated model output and multisatellite merges) that are evaluated with SHADOZ data.

Because each sonde is a new instrument and calibrated prior to launch, extensive *metadata*—data about the data—are transmitted with each record. These include ozonesonde and radiosonde serial numbers, composition of the sensing solution, final background current, and laboratory conditions for the calibration. Of note is that the SHADOZ data archiving protocol does not include centralized processing at GSFC. One reason for this is that SHADOZ has achieved ~3% total ozone accuracy and 5-15% precision throughout the profile by having station data suppliers use consensus-based procedures for operations and data-processing—see "SHADOZ Technological Accomplishments" on page 12 for more information. This practice empowers the operator–sponsor partnership in building capacity for ongoing data-taking at the station. A second reason is that distributed data processing by SHADOZ partners actively engaged in the Assessment of Standard Operating Procedures for Ozone Sondes (ASOPOS)[6] process should be more reliable than with central processing, where one "big mistake" is a risk.

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SHADOZ Spinoffs

As testimony to its success, several SHADOZ spinoffs should be noted. For example, SHADOZ has served as a data repository for several tropical field campaigns. The earliest campaign data in the SHADOZ archive is from the 1999 Indian Ocean Experiment (INDOEX) period,[7] including 25 profiles from NOAA's Aerosols99 transatlantic cruise and 53 profiles from the Kaashidoo observatory in the Indian Ocean. Extra soundings at the Irene, South Africa, SHADOZ station, and a small set from Lusaka, Zambia (15.4° S, 28.3° E) were collected with NASA support during the Southern Africa Regional Science Initiative (SAFARI)-2000.[8] Soundings retrieved over Manus Island, Papua New Guinea (in the western Pacific)—during the Coordinated Airborne Studies in the Tropics (CAST) campaign, which took place in the western Pacific in 2014—are the most recent additions to the campaign archive.

Another SHADOZ spinoff owes to the concept of a *strategic sonde network* (described in a 2011 paper in *Atmospheric Environment* by the lead author and others; DOI: *10.1016/j.atmosenv.2010.05.002*), to coordinate launches that address specific scientific questions. For example, coincident with several NASA-sponsored aircraft campaigns, several ozonesonde networks that lasted through the various campaigns were organized to answer questions on pollutant chemical sources and transport. These Intensive Ozonesonde Network Studies (IONS) have been assembled in support of Intercontinental Chemical Transport Experiment–North America (INTEX-NA),[9] Arctic Research of the Composition of the Troposphere from Aircraft

[6] ASOPOS was implemented in 2001, under the auspices of the World Meteorological Organization's (WMO) Global Atmosphere Watch (GAW) Programme with the intent of defining easy to follow operating procedures that can be consistently implemented to provide data of high quality that are comparable across the approximately 60 active global ozone sounding stations. Learn more at *https://www.fz-juelich.de/iek/iek-8/EN/Expertise/Infrastructure/ASOPOS/ASOPOS_node.html*.

[7] INDOEX was a multinational scientific study designed to measure the transport of air pollution from Southeast Asia into the Indian Ocean. To learn more, visit *http://www-indoex.ucsd.edu.*

[8] SAFARI 2000 was an international science initiative to study the linkages between land and atmosphere processes conducted from 1999-2001 in the southern African region. To learn more, visit *https://daac.ornl.gov/cgi-bin/dataset_lister.pl?p=18*.

[9] INTEX-NA was a major NASA science campaign to understand the transport and transformation of gases and aerosols on transcontinental and intercontinental scales and their impact on air quality and climate. Learn more at *https://www-air.larc.nasa.gov/missions/intexna/intexna.htm.*

and Satellites (ARCTAS),[10] and Studies of Emissions and Atmospheric Composition, Clouds, and Climate Coupling by Regional Surveys (SEAC4RS).[11]

GSFC and GMD partnered in organizing all of the IONS; the first three IONS networks were also coordinated with Environment Canada (now Environment and Climate Change Canada) and included up to seven Canadian stations. Daily launches were the norm in IONS, scheduled to coincide with Aura overpasses at approximately 1:30 PM local time. IONS data were posted to GSFC websites in SHADOZ format and distributed in near-real time to the participating science teams by the SHADOZ Archiver during the campaigns. Afterward, the data were transmitted to the Atmospheric Science Data Center (ASDC) at NASA's Langley Research Center (LaRC) and WOUDC. The complete IONS dataset numbers more than 1000 profiles—many for unique, previously unsampled North American locations.

The literature shows that positive response to the availability of SHADOZ data was immediate and that the impact has grown over time.

Scientific Contributions and Uses of SHADOZ Data

SHADOZ project personnel scan the literature annually for publications acknowledging use of SHADOZ data or referencing archival SHADOZ publications, such that the SHADOZ website contains ten full-text archival papers and lists hundreds of additional relevant publications. The literature shows that positive response to the availability of SHADOZ data was immediate and that the impact has grown over time. Scientific contributions fall into four broad areas:

- *Satellite validation, algorithm development, and the creation of profile climatologies*. An important milestone and major motivation for NASA to keep extending SHADOZ was the 2004 launch of Aura, with four ozone sensors onboard.[12] **Figure 2** displays over 20 satellite instruments that are being validated using SHADOZ data.

- *Climatological analyses recording vertical, temporal, and geographical ozone variability across the tropics and subtropics*.

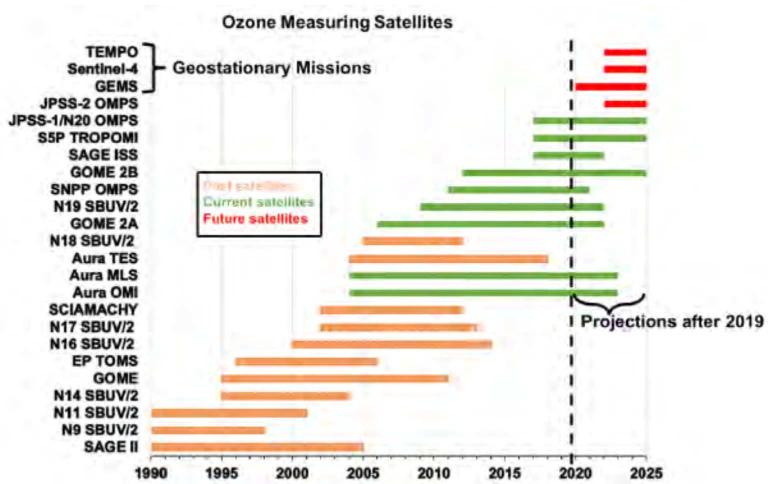

Figure 2. Timeline of past (orange bars), current (green bars), and future (red bars) satellite ozone-observing instruments that have used or will use SHADOZ data for validation. Expected launches and lifetimes beyond 2019 are indicated. **Note**: The y-axis lists commonly used acronyms for missions/instruments; all but one are either defined in the text or can be easily looked up online. N# is short for NOAA #, e.g., N19 stands for NOAA 19. **Image credit**: Debra Kollonige

- *Reference tropical ozone profiles for model intercomparisons that began around the year 2000*. In these exercises, chemical-transport and chemical-climate models use specified inputs and scenarios to evaluate model output for robust predictions and uncertainties.

- *Ozone trend studies in which data from multiple SHADOZ stations are often combined into one set of stratospheric profiles*.

The remainder of this section gives a representative sampling of important findings from papers listed at the SHADOZ website; refer to the SHADOZ website to learn more.

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[10] ARCTAS was an international effort to conduct intensive research in the Arctic, to better understand the changing atmospheric composition in the climatically sensitive regions near the North Pole. To learn more, visit *https://www-air.larc.nasa.gov/missions/arctas/arctas.html*.

[11] SEAC4RS was a field campaign based out of Houston, TX, to study how pollution and natural emissions are redistributed via deep convection throughout the troposphere and how these emissions impact atmospheric composition and climate. To learn more, visit *https://www-air.larc.nasa.gov/missions/seac4rs*.

[12] Refer to the special issues of the *Journal of Geophysical Research-Atmospheres* focused on Aura Validation published in 2007 and 2008 to learn more about how SHADOZ is used for satellite validation. To download these issues, see *https://agupubs.onlinelibrary.wiley.com/doi/toc/10.1002/(ISSN)2169-8996.AURA1*.

The Aerosols99 cruise discovered the so-called Atlantic ozone paradox, which refers to a greater tropospheric ozone column amount over the South Atlantic than over the North Atlantic during the West African biomass burning season.

SHADOZ Provides Answers: Where in the Atmosphere is Tropical Atlantic Ozone "Maximum"?

SHADOZ data were used to help resolve the location of a *zonal wave-one* pattern in total ozone seen by satellite. This pattern, which is so-named because the graph looks like standing wave-one (e.g., see top of **Figure 3**), was first pointed out in 1987, and was a motivating goal for SHADOZ. The question at the time was: *Is the additional 5-20 DU observed in total ozone over the tropical Atlantic relative to the Western Pacific located in the stratosphere, the troposphere, or both?* With the superior vertical resolution and zonal coverage of the SHADOZ sonde data, it became clear that the wave-one pattern resulted from a tropospheric ozone pattern (see middle of **Figure 3**), as Equatorial stratospheric ozone is zonally invariant.

SHADOZ Discoveries: The Tropical Atlantic Ozone Paradox, El Niño Complexities, and the Tropical Tropopause Layer (TTL)

Ozone in the free tropical troposphere has a lifetime of between a week and a month, which makes it an excellent dynamical tracer. The Aerosols99 cruise (mentioned earlier) discovered the so-called *Atlantic ozone paradox*, which refers to a greater tropospheric ozone column amount over the South Atlantic than over the North Atlantic during the West African biomass burning season—see bottom of **Figure 3**. Follow-on SHADOZ observations confirmed that South Atlantic tropospheric ozone is greater than its North Atlantic counterpart during the December–January–February period due to subsidence.

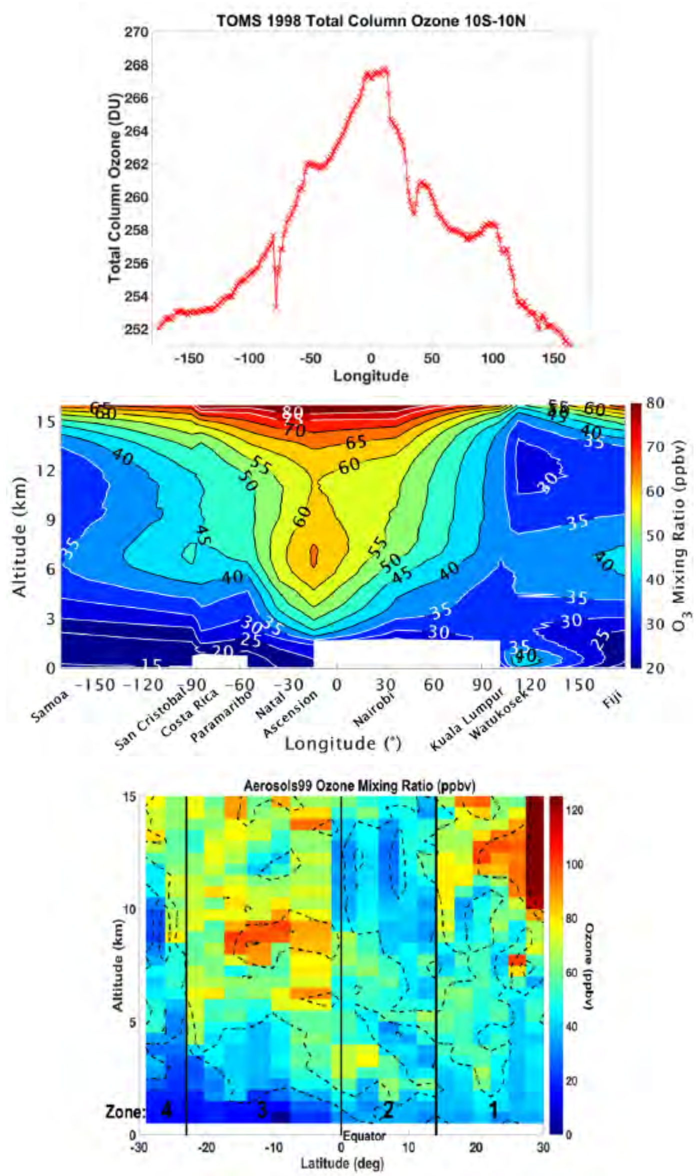

Figure 3. Top image, based on an average of 1998 EP/TOMS total ozone measurements, illustrates the *zonal wave-one* pattern. Middle image shows the zonal structure based on average ozone mixing ratios for the ten tropical SHADOZ stations (all located between 19° S and 19° N latitude), from soundings obtained from 1998–2017. Bottom image shows tropical Atlantic *ozone paradox* (discussed in text on pages 10-11) captured in the trans-Atlantic Aerosols99 cruise on NOAA's *Research Vessel Ronald H. Brown* during the northern tropical biomass fire season. Notice that ozone values are lower in the Northern Hemisphere where there are active fires (Zone 2 on map) than south of the Equator where there are no fires (Zone 3 on map). This then is the paradox, because the results are opposite from what one would expect. **Image credit**: *top, bottom*: Debra Kollonige; *middle*: Ryan Stauffer

The beginning of SHADOZ ozone measurements in 1998 coincided with the extremely strong 1997-98 El-Niño/Southern Oscillation (ENSO) event. El Niño warms temperatures in the tropical Pacific Ocean, and alters weather patterns worldwide. The 1997-98 event led to extreme drought over Southeast Asia, making the region more vulnerable to fires than usual. Indeed, there was a large wildfire outbreak in Indonesia at that time that could be observed from satellite observations [e.g., from the Total Ozone Monitoring Spectrometer (TOMS) on NASA's Earth Probe satellite, launched in 1996]. Many studies used satellite data to determine the source of the elevated ozone levels over southeast Asia at that time. Only SHADOZ ozonesonde observations obtained at the Watukosek (located in Indonesia) station revealed the complexity of the processes at work: the anomalous dynamical conditions over that area amplified increases in tropospheric ozone caused by fires burning in Indonesia. Since then, numerous publications have used SHADOZ data to document ENSO impacts on lower-stratospheric and free tropospheric ozone.

The *tropical tropopause layer* (TTL), or *tropopause transition layer*, is a zone at altitudes between ~14 and 18 km (~9 to 11 mi) and clearly distinct from both the troposphere and the stratosphere. This region was characterized in several studies published between 2002 and 2009, largely on the basis of SHADOZ ozone data. Investigations of the dynamical, chemical, and radiative properties of this region continue because the TTL is at the nexus of interactions between changing ozone and climate.

SHADOZ has been essential in formulating new, more-accurate ozone profile climatologies.

SHADOZ Data Contribute to New Retrieval Algorithms and Ozone Climatologies

SHADOZ has been essential in formulating new, more-accurate ozone profile climatologies. When combined with data from MLS, a full ozone profile climatology can be created. Several of these climatologies are currently being used in versions of the ozone retrieval algorithm used by TOMS, SBUV, OMI, the Ozone Mapping and Profiler Suite (OMPS) on the Suomi National Polar-orbiting Partnership, the Atmospheric Infrared Sounder (AIRS), on Aqua, and the TROPOspheric Monitoring Instrument (TROPOMI) on the European Copernicus Sentinel-5 Precursor satellite. The increased tropical longitudinal coverage provided by SHADOZ has led to a greater understanding of spaceborne instrument-derived ozone sensitivity in the troposphere. The tropical wave one pattern deduced from the SHADOZ data (described above) is used to validate tropospheric ozone maps from satellite studies. Without these data from a critical, dynamic region of the globe, it would be difficult to estimate errors and limitations in the satellite instruments.

Researchers have tried different approaches to tropospheric ozone climatologies with a goal of more-meaningful statistics for model evaluation. Perhaps the most innovative of these applies a machine learning technique called *self-organizing maps* (SOM). **Figure 4** displays four clusters of Ascension tropospheric ozone profiles that were created by SOM. Rather than a standard average (solid gray lines in Figure 4), these distinct shapes tend to correlate with different atmospheric conditions, so that the variations are more physically based.

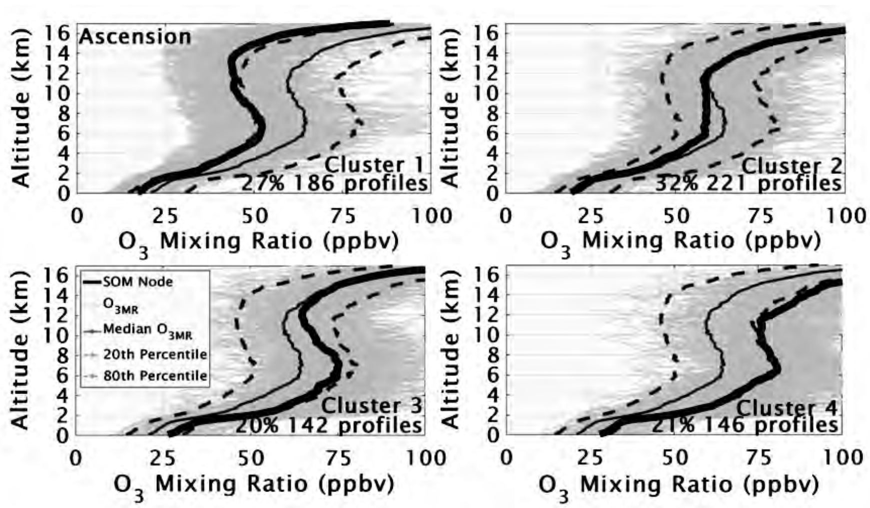

Figure 4. These ozone profiles were organized using the self-organizing map (SOM) technique discussed in the text. Data are shown for the Ascension Island SHADOZ station. The SOM technique identified four clusters for Ascension, with ozone mixing ratio profiles shown for each cluster in the four panels above. Approximately half the profiles are associated with means (black curve) that deviate from an overall mean (solid gray curve), with the twentieth to eightieth percentile range indicated by the dashed lines on either side. Examination of meteorological parameters (e.g., velocity potential, convective mass flux) indicates that for Ascension, Cluster 1 has the lowest ozone mixing ratios, and is associated with enhanced convective activity. Cluster 4, by contrast, has elevated amounts of ozone, corresponding to the peak period of African biomass fires upwind. **Image credit:** Ryan Stauffer

SHADOZ Data Contribute to Ozone and Related Assessments

The 20-year SHADOZ dataset, along with merged multi-satellite records, has given rise to dozens of ozone trend studies and an ongoing role for SHADOZ in the United Nations Environmental Programme (UNEP)/WMO

Ozone Assessments, and in the recently published Long-term Ozone Trends and Uncertainties in the Stratosphere (LOTUS; *https://events.spacepole.be/event/56/page/94-lotus-report*) and Tropospheric Ozone Assessment (TOAR; *http://www.igacproject.org/activities/TOAR*) reports.

Current questions being researched include:

- Is tropical tropospheric ozone increasing and—if so—in which geographical regions?
- Has ozone in the lowermost stratosphere really decreased in the past two decades?
- Are the main drivers for interannual ozone variability chemical or dynamical?

The reprocessed SHADOZ data display seasonal and regional differences in trends for free tropospheric and lower stratospheric ozone that are helpful in answering these and other important questions.

With an increasing number of satellites lasting a decade or more (see Figure 2), the tropical SHADOZ sonde data—with a fairly invariant stratospheric set of profiles—have been especially useful for detecting drift and biases among limb-sounding satellites and ground-based lidars. Conversely, a range of satellite–sonde offsets in the tropics points to possible biases among SHADOZ stations. As more satellites become operational, the ingestion of SHADOZ data into fast-turnaround data systems is accelerating the ongoing evaluation and intercomparison of many overlapping instruments.

As more satellites become operational, the ingestion of SHADOZ data into fast-turnaround data systems is accelerating the ongoing evaluation and intercomparison of many overlapping instruments.

SHADOZ Technological Accomplishments

The active participation of SHADOZ in efforts by the international ozonesonde community to standardize procedures and to improve accuracy and precision has had a major impact on global ozone measurements. SHADOZ has helped to raise the quality of sonde measurements in several ways. First, SHADOZ specified that only one type of ozonesonde instrument, the *electrochemical concentration cell sonde* (described earlier), be used at SHADOZ stations. More important, the SHADOZ team has become a leader in the international ozonesonde intercomparisons called the Jülich Ozonesonde Intercomparison Experiments (JOSIE), organized by the Forschungszentrum (FZ)-Jülich (Germany), with Herman G. J. Smit as PI of the World Calibration Center for Ozone Sondes (WCCOS), also in Germany. WCCOS is organized around an ozonesonde test chamber that accommodates four instruments at once and simulates typical ozone, pressure, and temperature profiles.

SHADOZ and the JOSIE Campaigns

The first JOSIE campaign with SHADOZ participants took place in 2000. An important outcome was the characterization of systematic offsets in ozone readings when different techniques were used. One source of the biases is differences in sonde type—i.e., there are two ozonesonde manufacturers, Science Pump Corporation (SPC) and Environmental Science (EN-SCI), and each company designs its ozonesonde slightly differently. Another source of bias arises from differences in the chemical composition of the sensing solution. These two sources of bias show up in similar ways. In other words, there is always a difference in measured ozone when the same solution is used in the two types of instruments as well as when different solution types are tested with a single type of instrument. These biases were consistent with offsets observed in the SHADOZ record. That is, when the stratospheric segment of tropical SHADOZ profiles were referenced to an all-SHADOZ mean, the instruments that were biased low (high) in JOSIE-2000 were also lower (higher) in the SHADOZ data.

The findings of JOSIE-2000 along with the results from a 2004 field experiment, the Balloon Experiment on Standards for Ozone Sondes (BESOS), were the basis for a publication on recommended instruments, solutions, and best practices in sonde preparation: WMO/GAW Report No. 201 (*https://www.wmo.int/pages/prog/arep/gaw/documents/GAW_201.pdf*) by the ASOPOS team. The adoption of standard operating procedures by stations worldwide, along with reprocessing of older sonde data (see "Reprocessing" on page 14), has reduced station biases and overall uncertainty for the total column ozonesonde measurement to 3-5% or better.

Nonetheless, during the past decade, as the time-series for SHADOZ and other sonde records expanded, several issues emerged that called for a new round of chamber tests. Among these were apparent changes in the EN-SCI sonde—which changed manufacturers twice between 2012 and 2015. In addition, several SHADOZ stations had changed the solution type between 1998 and 2010, which led to artifact trends in the time-series. (An example is shown in **Figure 5**—described in detail below). Variations among stations in the prelaunch sonde background ozone current sometimes propagated to artifact low ozone values near the tropopause.

JOSIE–SHADOZ Experiment

To address these issues, a JOSIE–SHADOZ Experiment was conducted in 2017, at the WCCOS (described in a 2019 article by the lead author *in Bulletin of the American Meteorological Society, https://journals.ametsoc.org/doi/pdf/10.1175/BAMS-D-17-0311.1*). The test included all the instrument–solution combinations used in SHADOZ and a range of SPC and EN-SCI instrument batches. As a bonus, the Vienna Convention Trust Fund operated by the United Nations Environment Programme supported eight SHADOZ operators (four from the tropical Americas, two each from Africa and southeast Asia) to participate in JOSIE-SHADOZ operations and special training. JOSIE participants and an independent referee team examined 80 profiles from the test chamber to conclude that:

- The biases among the instrument-sensing solution combinations reported for JOSIE-2000 were confirmed in 2017;
- careful handling with dry air (to counteract humid conditions at most SHADOZ sites) during pre-launch calibration is essential for high-precision measurements; and
- there were no consistent problems with EN-SCI (instruments from 2011-2017 were evaluated) but periodic WCCOS tests for both EN-SCI and SPC instruments are recommended going forward.

There is ongoing evaluation of the JOSIE–SHADOZ dataset. Related laboratory and field tests have been conducted by NOAA, NASA, and Environment and Climate Change Canada. The ASOPOS team is updating the

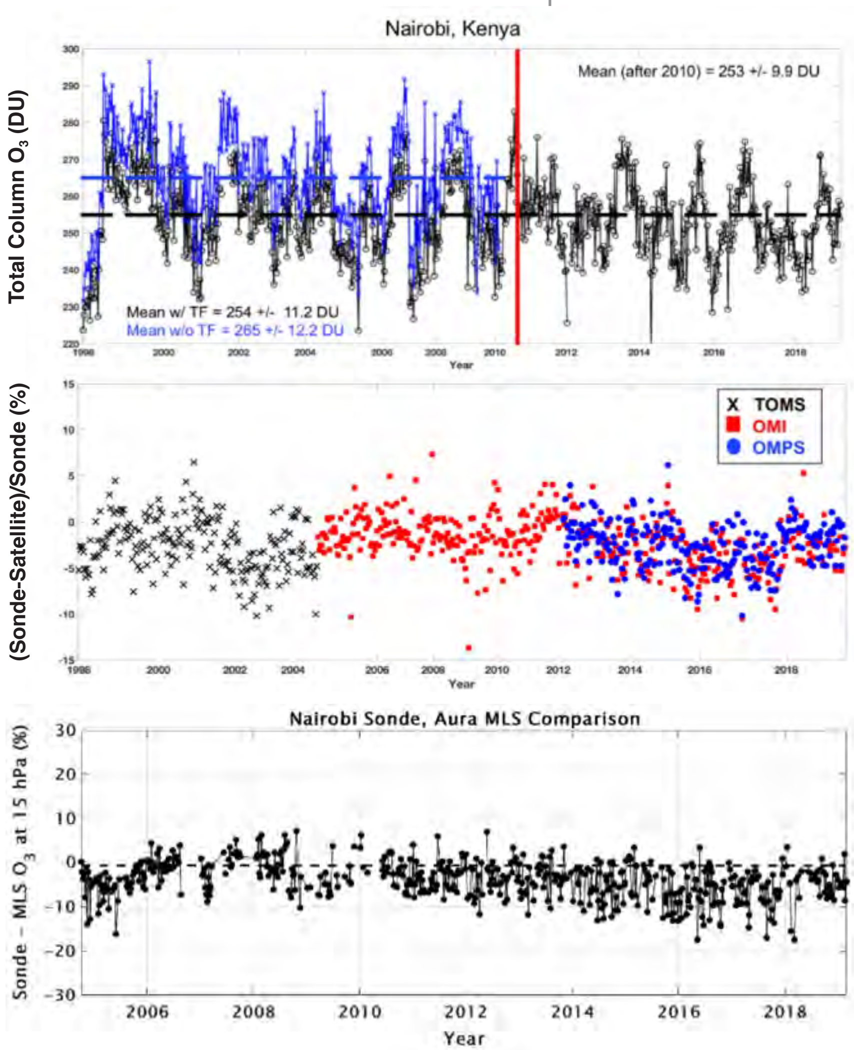

Figure 5. The top graph shows time-series of total column ozone (TCO) from SHADOZ sondes over Nairobi, Kenya. The discontinuity in the data that is evident after 2009 is the result of adoption of the WMO-recommended instrument–solution combination, after which the mean TCO decreased by 11 DU. Reprocessing of pre-2009 data homogenizes the record. The middle graph shows comparison (% offset) of TCO from the complete reprocessed data to satellite-measured TCO—with different symbols representing EP/TOMS, Aura/OMI and Suomi NPP/OMPS overpass measurements. The bottom graph shows offsets between ozone measured from the sondes and MLS on Aura overpasses (2005–2018) in percent at the 15 hPa level. These offset amounts are typical for the mid-stratosphere. **Image credits**: *Top, middle*: Debra Kollonige; *bottom*: Ryan Stauffer

WMO/GAW No. 201 Report and adding a definitive assessment of ozone profile uncertainties. The results will apply to all soundings, not only those in the tropics.

Reprocessing

Because instruments and procedures change over time, dozens of sonde stations worldwide have records compromised by discontinuities—as illustrated in the top image of Figure 5. The ASOPOS team has documented procedures for reprocessing, or "homogenizing," sonde records to correct for the inconsistencies (*http://www-das.uwyo.edu/~deshler/NDACC_O3Sondes/O3s_DQA/O3S-DQA-Guidelines%20 Homogenization-V2-19November2012.pdf*). The guidelines include so-called transfer functions (labeled TF in Figure 5) among different instrument and solutions based on the JOSIE and field experiment results. Records for roughly 30 ozonesonde stations have been reprocessed in the past 5 years—including 14 SHADOZ stations. Every single profile was evaluated and reprocessed to produce the version 6.0 SHADOZ data that were released in March 2019. Uncertainties in each ozone reading are also posted at the SHADOZ website. Reprocessing details, uncertainties, and comparisons of total column and profile ozone before and after reprocessing appear in four archival papers at the SHADOZ website.

Records for roughly 30 ozonesonde stations have been reprocessed in the past 5 years—including 14 SHADOZ stations. Every single profile was evaluated and reprocessed to produce the version 6.0 SHADOZ data that were released in March 2019.

The middle image of Figure 5 shows an updated comparison of total column ozone (TCO) data from reprocessed SHADOZ profiles at Nairobi, Kenya, relative to observations from OMI and OMPS. Comparisons between reprocessed stratospheric ozone measurements from the Nairobi sondes and MLS retrievals in the middle stratosphere are displayed in the bottom image of Figure 5.

Summarized in **Figure 6** are the mean agreements in TCO between the OMI–OMPS overpasses and the reprocessed sonde measurements at all 14 long-term SHADOZ stations. The agreement for all but one station is within 3%. In contrast, the first comparison of SHADOZ TCO measurements and satellite overpasses (at that time from TOMS), published in 2003, showed that the mean sonde–satellite offset was 7-8%, with half the stations in disagreement by more than 10%. The improved metrics for the reprocessed data explains much of the user community's enthusiasm for ozonesonde observations.

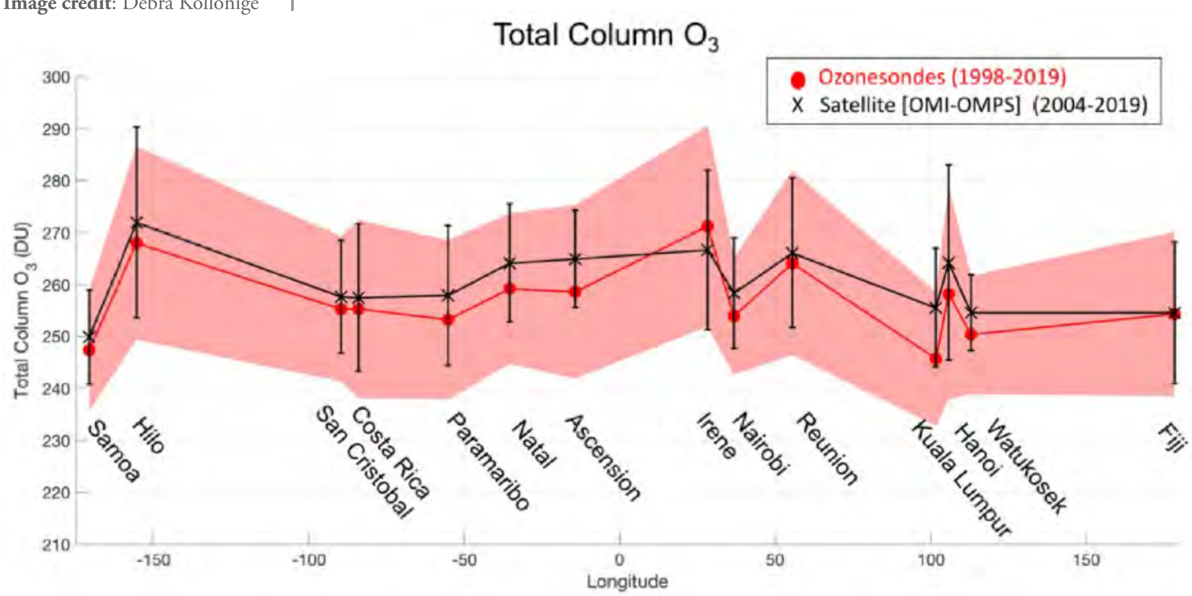

Figure 6. Longitudinal cross section of reprocessed ozonesonde total column O_3, or TCO, circles with ±1 σ (shading)] and the collective mean of OMI–OMPS overpass columns [x symbol with ±1 σ (bars)]. The numbers of ozonesonde profiles used for each representative station total column O_3 are in the Table on page 7. **Image credit**: Debra Kollonige

Conclusion

This retrospective on 20 years of SHADOZ observations has described how a strategic ozonesonde network operating in the previously data-sparse tropics has played a leading role in the global ozone measurements community. A well-coordinated team with an open, user-friendly website has produced an archive of ozone profiles with impact extending far beyond the original SHADOZ objectives. The scientific findings have been rich and diverse, creating a growing demand for high-resolution measurements in a region of the atmosphere that is highly sensitive to perturbations in ozone and climate. The project is looking for sponsors and operators to extend SHADOZ to underrepresented regions, e.g., west Africa, south Asia.

The process of periodic evaluation of sonde performance through the ASOPOS, NDACC, and other groups, along with user feedback, has led to greater standardization of technique. In addition, reprocessing of SHADOZ data yields sonde data in better agreement with independent, ground-based instruments, so the data better meet the rigorous requirements of the satellite retrieval and trends communities. Ozonesonde instrumentation is not static, and ongoing evaluations, reprocessing, and periodic lab and field evaluations of sonde performance will be necessary to maintain the highest possible standards. Indeed, the ozonesonde community is only beginning to address the effect of changing radiosonde instruments on ozone measurements.

By playing a leading role in a global sonde network of approximately 100 stations, SHADOZ has transformed a 50-year-old technology into an integral element of twenty-first-century ozone observations.

SHADOZ exemplifies the success of a strategically designed network built on a dedicated community of technicians, sonde researchers, sponsors, and data users. By playing a leading role in a global sonde network of approximately 100 stations, SHADOZ has transformed a 50-year-old technology into an integral element of twenty-first-century ozone observations.

Acknowledgments

SHADOZ grew out of a 1997 NASA–NOAA meeting held in Silver Spring, MD, with **Anne Thompson** (PI), **Jack Kaye**, and **Pawan "P. K." Bhartia** [all from NASA], and **A. J. Miller** [NOAA] in attendance.

The authors of this article are grateful for the steady support received from NASA's Science Mission Directorate and, in particular, the support of the program managers for the Upper Atmosphere Research Program (UARP) at NASA Headquarters: **Michael Kurylo**, 1998–2007 and **Kenneth Jucks**, [2008–present]. The authors also wish to recognize **Jacquelyn Witte** [GSFC/Science Systems and Applications, Inc. (SSAI)], whose user-friendly and informative SHADOZ Archive and Website contributed greatly to the success of SHADOZ from 1998 through April 2019. Article co-author **Debra Kollonige** [GSFC/SSAI] has recently assumed the Archiver responsibilities.

Remembering Apollo from an Earthly Point of View: NASA Celebrates Fiftieth Anniversary of Apollo 11 Moon Landing

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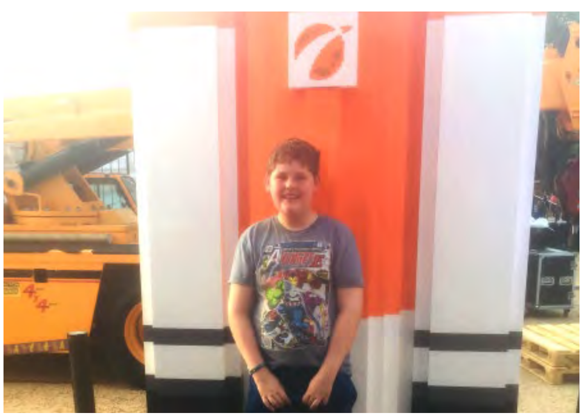
Introduction

The Smithsonian's National Air and Space Museum hosted a celebration on the National Mall July 18–20, 2019 in Washington, DC, to honor the fiftieth anniversary of the Apollo 11 Moon landing. NASA participated and had numerous tents set up with a variety of exhibits and hands-on activities. NASA's Science Mission Directorate (SMD) and Science Support Office (SSO) assisted the NASA Headquarters (HQ) Office of Communications in planning and staffing the event. In addition to NASA, participants and sponsors included Lego (see **Photos 1-2**), The Boeing Company, Raytheon Company, and the Public Broadcasting System (PBS) Kids *Ready Jet Go* (*https://pbskids.org/readyjetgo*) program/app.



Photos 1-2. The Lego exhibit provided bins of multicolored Legos to entertain creative designers of all ages who visited [*top*] and a 20-ft (~6.1-m) tall Lego model of the Space Launch System (SLS) rocket [*bottom*] that will carry humans back to the Moon, made up of 198,000 Lego pieces—and weighing 1000 lbs (~454 kg). For perspective, the boy in the photo (Brady Ward) is ~6-ft (~1.8-m) tall—and the photo doesn't capture the whole SLS structure. There was also a 38,000-piece, life-sized Lego Apollo Astronaut model on display [*not shown*] that drew large crowds. **Image credits**: *Top*: NASA/Connie Moore, *bottom*: Alan Ward

By all accounts, it was an extremely hot weekend to be out on the National Mall—even by "July in DC" standards. It was originally projected that 50,000 people would participate over the three days of the event; however, actual participation was somewhat lower due to the persistent and extreme heat and humidity.

Event Overview

The focus of the event was the Apollo 11 anniversary, which included a launch reenactment on the evenings of July 19 and 20—see *Apollo 11 Launch Retrospective and Reenactment* on page 20. Therefore, most of the NASA activities focused on the Moon, where NASA has ambitious plans to return by 2024; Mars, where NASA hopes to eventually explore, using a renewed and sustained human presence on the Moon and in lunar orbit as a "stepping stone" to get there; and the International Space Station (ISS)—see **Photo 3**.

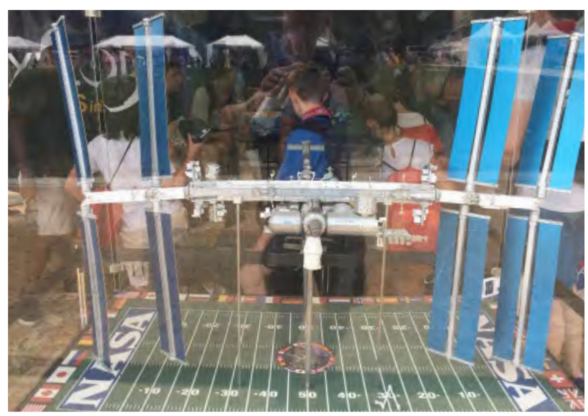


Photo 3. One of the ISS-themed tents included a model of the ISS enclosed in a plastic case. The football field below [100 yards (~91.4 m)] is intended to give perspective on the approximate size of the station. The ISS currently hosts six NASA Earth science instruments. **Photo credit**: Alan Ward

However, there would be no "Moon" without Earth to hold it in orbit, and Earth is part of the larger Solar System, so it was fitting that there were also a number of Earth-focused activities. These activities are the focus of the remainder of this article, with the primary emphasis on the exhibits in NASA's *Earth Tent*, described in the following pages.

NASA's Earth Tent Showcases NASA's Earth Science Research

The inflatable Earth Tent—shown in **Photos 4-5**—was clearly a distinctive presence on the Mall, and was a big draw during the Apollo 11 fiftieth anniversary celebration.

Inside the tent was a series of hands-on activities covering major NASA Earth science research areas, including exhibits highlighting NASA's research in the realms of Ice, Land, Water, and Air/Carbon; a Global Learning and Observation to Benefit the Environment (GLOBE) exhibit focused on citizen science; and a quiz to test visitors' knowledge of the Moon and Earth.

Photo 4-5: These photos show NASA's Earth Tent on the National Mall viewed from the outside during the Apollo 11 fiftieth anniversary celebration [*top photo*], and from inside [*bottom photo*]. There was a steady flow of visitors to the Earth Tent throughout the event. **Photo credit:** NASA

Ice Exhibit

The Ice exhibit included a demonstration of how the Advanced Topographic Laser Altimeter System (ATLAS) on the Ice, Cloud and land Elevation Satellite-2 (ICESat-2) collects elevation data. For safety, in lieu of a laser, the model—shown in **Photo 6**—used a motion detector, which employs the same measurement principle with ultrasound waves that a laser does with visible light: signals from the instrument bounce off objects on Earth's surface, return to the sensor, and their round-trip travel time is counted, thereby enabling us to calculate the height of the object below the satellite. For this demonstration, Legos® and a plastic glacier model were used to represent different objects the satellite passes over as it moves along Earth's surface. There was also a Gravity Recovery and Climate Experiment Follow-On (GRACE-FO) activity

Photo 6. Jack Lacey [NASA HQ] and **Chris Shuman** [University of Maryland, Baltimore County/NASA's Goddard Space Flight Center (GSFC)] demonstrate the ICESat-2 mission measurement, as part of the NASA Ice exhibit. **Photo credit:** NASA

that used three large ice cubes to represent the GRACE-measured ice loss in Greenland, Antarctica, and Alaska.[1] Each of the large cubes was filled with smaller cubes, each representing a gigaton of ice loss.[2] Finally, there was an activity with a series of Landsat images of Pine Island Glacier in Antarctica used to illustrate iceberg calving events between 2001 (Landsat 7) and 2019 (Landsat 8); all images were obtained in early January. Another Landsat image was also shown that was obtained on November 7, 2018, the same day that an Operation IceBridge flight observed Iceberg B-46—just over a week after it had broken free from Pine Island Glacier.

Land Exhibit

The Land exhibit included an "interactive cubes" activity, demonstrating land-use changes over time using four different Landsat image time series—see **Photo 7.**

Photo 7. The "interactive cubes" were part of the Land exhibit. The task for visitors was to put one or more of the four sets of Landsat images shown on the cube faces in chronological order. **Photo credit**: Alan Ward

[1] This measurement was done using data from the original GRACE mission—not GRACE–FO—because there is not yet enough GRACE–FO data to update the calculation.
[2] To help conceptualize how much water a gigaton represents, it is equivalent to the amount of water in 400,000 Olympic-sized swimming pools, and would fill the volume (i.e., height x width x depth) of 2.5 Empire state buildings.

Also related to Land, but outside and adjacent to the Earth Tent, was a large (8 x 10-ft) Landsat map of the Chesapeake Bay region that visitors could use to identify their homes and other familiar locales that are easily recognized from space, e.g., airports—see **Photo 8**. The Land exhibit also featured interactive tabletop puzzles showcasing Landsat images of Earth—see **Photos 9-10.**

Photo 8. Just outside the Earth Tent, **Allison Nussbaum** [Science Systems and Applications, Inc./GSFC] endures the heat to explain the Landsat map of the Chesapeake Bay to some NASA Land exhibit visitors. **Photo credit:** NASA

Photos 9-10. Two circular jigsaw puzzles depicting Earth were part of the NASA Land exhibit. This was a popular attraction inside the Earth Tent. The two groups shown here were among the many visitors who persevered and successfully put Earth back together. (There was a circular Moon jigsaw puzzle [*not shown*] at one of the other Moon-themed tents.) **Photo credit**: Alan Ward

Water Exhibit

The Water exhibit featured a Global Precipitation Measurement (GPM) mission activity and a Surface Water and Ocean Topography (SWOT) mission quiz on an *iPad*, with an accompanying SWOT map and information handout—see **Photo 11**. The GPM mission contributes to advancing our understanding of Earth's water and energy cycles, improves the forecasting of extreme events that cause natural disasters, and extends current capabilities of using satellite precipitation information to directly benefit society. The SWOT satellite mission brings together U.S. and French ocean-ographers and hydrologists and international partners to make the first global survey of Earth's surface water, observe the fine details of the ocean's surface topogra-phy, and measure how water bodies change over time.

Photo 11. Laura Lorenzoni [NASA HQ] guides two young Earth Tent explorers through the NASA Water exhibit, which included a GPM mission activity and information on the upcoming SWOT mission. **Photo credit:** NASA

Air/Carbon Exhibit

The Air/Carbon exhibit featured a model of the Orbiting Carbon Observatory 3 (OCO-3) instrument. OCO-3, which is mounted on the International Space Station, and is designed to investigate important questions about the distribution of carbon dioxide (CO_2) on Earth as it relates to growing urban populations. The exhibit highlighted an example of the detailed CO_2 measurements NASA makes over cities, as well as the changing patterns of fossil fuel combustion, globally. The exhibit also included a visualization of how CO_2 has increased since 2002—see the computer screen in **Photo 12** on page 19. There were also a variety of handouts related to carbon, OCO-3, and OCO-2 (the predecessor mission to OCO-3) that visitors could take to learn more.

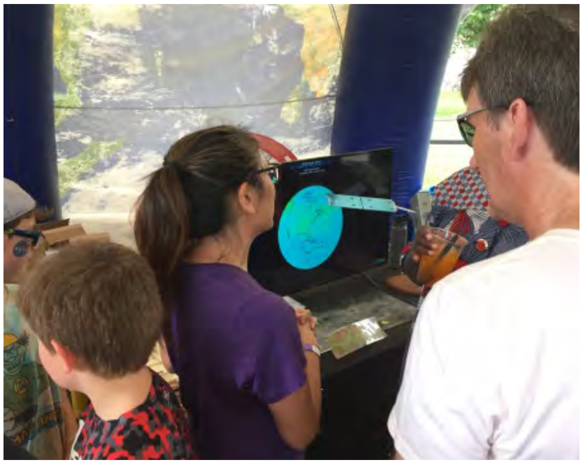


Photo 12. Visitors to the Earth Tent experience the NASA Air/Carbon exhibit, where they learned about NASA's CO_2 measurements. **Photo credit:** NASA

GLOBE/Citizen Science Exhibit

The GLOBE program hosted a table inside the tent to explain and promote NASA's citizen science activities and opportunities, including how anyone over age 13 can collect environmental observations in support of NASA science. Visitors were shown the *GLOBE Observer* app (available for both iOS and Android platforms), which helps them observe clouds (to match with satellite data), mosquito habitats (to support model forecasts of where mosquito-related disease outbreaks could occur), land cover (to provide verification data for satellite-based land cover maps), and tree height (to help verify ICESat-2 data).[3]

Earth and Moon Quizzes

In addition to the four main exhibit areas that have been described, there was a Quiz area to test visitors' knowledge of the Moon and Earth. Each quiz board, created by SMD/SSO staff, contained 10 multiple-choice questions—see **Photos 13-14**. Visitors could select an answer to each question by rotating a dial. Once all questions were answered, a flap at the bottom of the quiz could be opened to reveal the correct answers.

Other Earth Tent Highlights

Another popular item distributed by SMD was a lithograph of the Moon "photobombing" Earth, taken by the Earth Polychromatic Imaging Camera (EPIC) on the Deep Space Climate Observatory (DSCOVR) satellite. From its unique Earth-observing vantage point

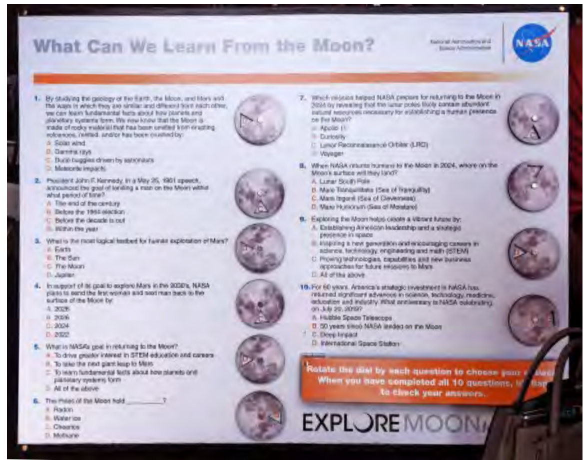


Photo 13-14. Quizzes on "What Can We Learn from the Moon?" [*top*] and "How Well Do You Know Earth and Moon?" [*bottom*] greeted visitors as they entered the Earth Tent. **Photo credit:** NASA

approximately one-million miles (~1,609,000 km) out in space at the *L1 Lagrange Point*[4]— roughly twice a year, EPIC captures the rarely seen far side of the Moon and Earth together in an image. This lithograph helped visitors to the Earth Tent draw a connection between NASA's ongoing Earth science mission and its goal of returning humans to the Moon by 2024.

The Earth Tent also featured a demonstration of NASA's *Eyes on the Earth* interactive application, which enables users to monitor Earth's vital signs, including sea level height, atmospheric carbon dioxide concentration, and Antarctic ozone. Users could trace the movement of water around the globe, spot volcanic eruptions and forest fires, locate the hottest and coldest places on Earth, and explore geolocated satellite images of recent events, including algal blooms, superstorms, and wildfires.

[3] To learn more about *GLOBE Observer* and citizen science, see "GLOBE Observer: Citizen Science in Support of Earth System Science" in the November–December 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 6**, pp. 15–21—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/Nov_Dec_2017_color_508.pdf#page=15*].

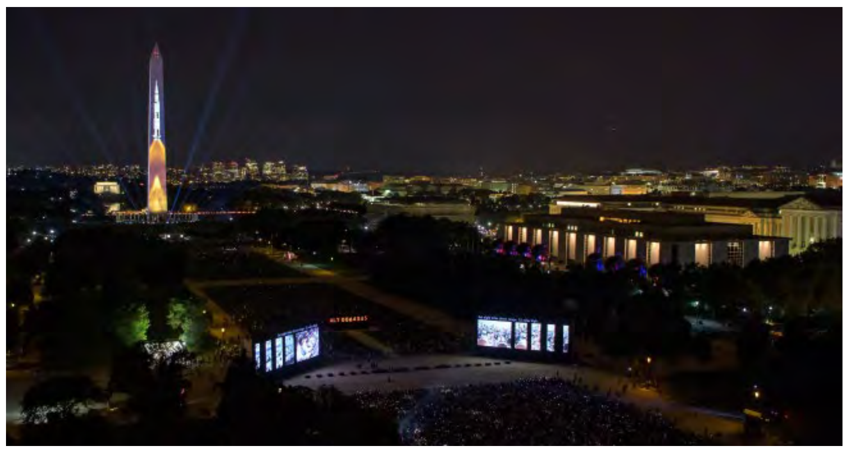
[4] In celestial mechanics, the Lagrange points, or *libration points*, are the points near two large bodies in orbit where a smaller object will maintain its position relative to the large orbiting bodies. There are five such points in the Earth–Sun system. DSCOVR is at the *L1-point*, between the Earth and the Sun, about one million miles from Earth.

Apollo 11 Launch Retrospective and Reenactment

As part of the fiftieth anniversary of the Apollo 11 mission on Friday and Saturday evenings (July 19-20) the National Air and Space Museum presented a 17-minute show called, *Apollo 50: Go for the Moon*, which combined full-motion, projection-mapping artwork on the east face of the Washington Monument and archival footage to recreate the launch of Apollo 11—see photo below—and tell the story of the first crewed Moon landing.

The lead author of this article and his family were among those in the crowd in front of the Monument on an oppressive Saturday evening in Washington, DC, waiting for the "big show," which we'd heard was spectacular from friends who attended the night before. We spent some time in the Smithsonian's Air and Space Museum, which had Apollo 11 anniversary events going on all through the evening. Then, at about dusk, we headed down the Mall to find a spot in front of the Monument to watch the show.

While we were waiting, we were treated to a lightshow from Mother Nature, courtesy of a rogue thunderstorm that passed perilously close to the Mall. We worried that we might get rained out, but in the end the cell narrowly avoided us. My family—and several thousand of our new "friends"— remained dry and the main event went off without a hitch. I can attest that it was well worth enduring the heat of the day and the crowds at night to be part of history—and that the sound of the simulated launch was quite impressive!



A reenactment of the launch of Apollo 11 was projected on the east side of the Washington Monument on the evenings of July 19 and 20. The show drew large crowds to the National Mall both nights to watch. The event was put on by the National Air and Space Museum. The footage can be viewed at *https://www.youtube.com/watch?v=R7ayx7CuKFs*. **Photo credit:** NASA/Bill Ingalls

NASA in Your Life Tent

Located a few tents down the Mall (i.e., walking toward the Capitol) from the Earth Tent, the *NASA in Your Life* tent was a collaborative effort aimed at demonstrating how NASA's research endeavors ultimately contribute to everyday life through technology transfer and spinoffs. In addition to two Earth science-based experiments and a video presentation displayed on a monitor, the NASA in Your Life tent featured four display cases containing spinoff materials and banner signs to explain how different areas of NASA contribute to improving the quality of daily life for the public.

Conclusion

Overall, NASA's involvement in the Apollo 11 fiftieth anniversary celebration on the National Mall, which took considerable logistical planning to orchestrate, was a success. Despite the excessive July heat and humidity, there was still a good turnout. Armed with fans and lots of water, staff and visitors to the Earth Tent and other activities stayed in good spirits throughout the event. It is clear that the public still experiences a sense of wonder when it comes to learning about NASA's endeavors. On the whole, they seemed genuinely appreciative of NASA's exhibits and expressed gratitude for its participation in this event.

The anniversary was an opportunity to look back on a historic moment when the world watched the first human walk on the Moon's surface and take "one small step for (a) man, one giant leap for Mankind."[5] It was also a chance to look forward to NASA's plans to return to the Moon to continue on to Mars, and ultimately, as far out into the Universe beyond as can be practicably implemented. Last but certainly not least in the context of *The Earth Observer*, it was also a chance to display NASA's diverse Earth science research endeavors, aimed at learning more about Earth, the planet around which the Moon orbits—and the one we call home. ■

[5] Learn more about the possible origins of Armstrong's famous quote upon stepping on the surface of the Moon—and the possibility that he has been slightly misquoted all these years at *https://time.com/5621999/neil-armstrong-quote*.

Summary of the Fiftieth ASTER Science Team Meeting

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Introduction

The fiftieth Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Science Team Meeting [ASTM] was held June 10-12, 2019, at the Japan Space Systems (JSS) offices in Tokyo, Japan. The year 2019 also marks the twentieth anniversary of the launch of ASTER on the Terra platform (December 1999), so the meeting had twice the cause for celebration. Altogether, there were 41 people, from both Japan and the U.S. that participated in the meeting. U.S. participants were from NASA/Jet Propulsion Laboratory (JPL), NASA's Goddard Space Flight Center (GSFC), U.S. Geological Survey (USGS), University of Hawaii (UH), and University of Pittsburgh (UP). From Japan, participants were from JSS, Ibaraki University (IU), Nagoya University (NU), University of Tokyo (UT), National Institute of Advanced Industrial Science and Technology (AIST), National Institute for Environmental Studies (NIES), Geological Survey of Japan (GSJ), Remote Sensing Technology Center of Japan (RESTEC), and University of Tsukuba (UTs). The goals of the meeting were to:

- review the pending release of the Global Digital Elevation Model (GDEM) Version 3;
- review the status of the data acquisition programs; and
- discuss the need for future updates to the radiometric calibration coefficients, based on field campaigns and onboard calibration sources.

After beginning with a brief history of the development of ASTER and the activities of the ASTM, this article summarizes the fiftieth ASTM meeting. Interested readers can contact the author to gain access to the agenda and full versions of the presentations summarized here.

Brief History of ASTER

ASTER has its roots in several moderate-resolution imaging sensors. The Landsat instruments (Multispectral Scanner and Thematic Mapper) had developed a large and devoted user community comfortable with analyzing multispectral data.[1] The second most used data were provided by the French Satellite Pour l'Observation de la Terre (SPOT) instruments.[2] Between 1992 and 1998 the Japanese Ministry of International Trade and Industry's (MITI) Japan Earth Resources Satellite–1 (JERS-1) Optical Sensor (OPS) instrument acquired three bands of VNIR data, four bands of shortwave infrared (SWIR) data, and along-track stereo data.

The Earth Observing System's (EOS) ASTER program began as two instruments proposed separately by the U.S. and Japan in the 1980s. The U.S. proposed the Thermal Infrared Ground Emission Radiometer

[1] To learn more about Landsat's instruments, see "The Living Legacy of Landsat 7: Still Going Strong After 20 Years in Orbit" in the July–August 2019 issue of *The Earth Observer* [**Volume 31**, **Issue 4**, pp. 4-15—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Jul_Aug_2019_final_color_508_0.pdf#page=4*].
[2] SPOT has 10–20 m (~33–66 ft) visible-and-near-infrared (VNIR) wavelength data, and cross-track stereo observing capabilities.

Participants of the fiftieth ASTER Science Team Meeting. The ASTER quilt displayed in front was made by Yasushi Yamaguchi's [NU—*Japanese ASTER Science Team Leader*] wife, Mrs. Yamaguchi, in 1992, on the occasion of the fourth ASTM held in Tsukuba, Japan. **Photo credit**: Tetsui Tachikawa [JSS]

(TIGER), a fourteen-channel imager plus a profiling spectrometer.[3] At the same time, Japan's MITI was designing and proposed the Intermediate Thermal Infrared Radiometer (ITIR) with five shortwave infrared (SWIR) bands and four thermal infrared (TIR) bands as a follow-on to JERS-1. Starting in 1988 a joint U.S. and Japanese ITIR/TIGER Science Team worked to develop a compromise design for a VNIR-SWIR-TIR instrument to go on NASA's EOS AM-1[4] platform (renamed Terra after launch). The number of TIR bands was increased to five; the number of SWIR bands was increased to six; spatial resolution was decided; VNIR band 3 was selected for the along-track stereo; and bandpasses of all the channels were determined. Following six ITIR/TIGER Science Team Meetings in the late 1980s, the newly designed instrument was named the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), and the first ASTER Science Team Meeting was held in November 1990, in Pasadena, CA.

For the next fourteen years, two ASTMs were held each year, alternating between Japan and the U.S. Starting in 2013 the next eight meetings were held in Tokyo at the request of the Japanese team. Until the 1999 launch of Terra, the AST was primarily concerned with the instrument design, creating the data-processing algorithms and software, creating the data acquisition scheduler, helping design the data processing system with interfaces between Japan and the U.S., and promoting potential uses of the data, once they became available. After the launch of the instrument, however, new working groups were formed, centering on science and applications, data calibration and validation, verification of the production algorithms, and outreach to the general science community. The fiftieth ASTM maintained this structure, with working groups reporting on the previous year's status and accomplishments.

Opening Plenary Session

Yasushi Yamaguchi [NU—*Japanese ASTER Science Team Leader*] and **Michael Abrams** [JPL—*U.S. ASTER Science Team Leader*] opened the meeting and welcomed participants. To highlight the fiftieth meeting, Yamaguchi presented a historical archive of pictures from many previous meetings. The Team then observed a moment of silence to remember several team members who passed away since the beginning of the project, 30 years ago. Abrams highlighted ASTER science presentations and posters from various professional meetings over the past year. ASTER's presence at the 2018 Fall American Geophysical Union (AGU) meeting held in Washington, DC, was particularly noteworthy, with 35 contributions using ASTER data. Of particular interest to all participants was the status of the Diplomatic Note, which formally extended the ASTER mission for an additional seven years after October 2019, when the previous agreement was due to expire. The previous note, signed by the U.S. State Department, and the Japan Ministry of Foreign Affairs, confirms the terms of the 1999 Memorandum of Understanding, detailing the roles and responsibilities of NASA and the Ministry of Economy, Trade and Industry (METI) to jointly operate the ASTER project. It is expected that the new Diplomatic Note will be executed before October 2019. In the U.S., the next Earth Science Senior Review[5] proposal will be submitted to NASA in March 2020 for an additional three years of extended mission funding. The Terra project has scheduled a science meeting in September 2019 to discuss and coordinate Terra's Senior Review proposal submission.

Sticker commemorating 100,000 orbits of Terra. **Photo credit**: Sticker designed by Tassia Owen [GSFC]; photo of sticker taken by Michael Abrams

Jason Hendrickson [GSFC] reviewed the status of the Terra platform. All systems are functioning nominally. Terra had to execute four collision-avoidance maneuvers over the past 12 months—about an average annual number. The spacecraft has sufficient fuel to maintain its current orbital Equatorial crossing time until late 2022. On October 6, 2018, Terra achieved a milestone of orbit number 100,000. To mark the milestone, Terra was featured in an article on the NASA Homepage. The team also produced commemorative stickers—shown above.[6]

[3] In the late 1970s JPL operated an airborne Thermal Infrared Multispectral Scanner (TIMS). In 1981, TIMS was one of the "strawman" instruments proposed to be part of *System Z**, which envisioned several large polar-orbiting Earth Science platforms maintained by the Space Shuttle in a manner similar to the Hubble Space Telescope. As the Earth Observing System (EOS) concept evolved in the late 1980s, however, the instrument design was refined and became known as TIGER.
*To learn about *System Z*, read "The Early Beginnings of EOS: 'System Z' Lays the Groundwork for a Mission to Planet Earth" in the September–October 2008 issue of *The Earth Observer* [**Volume 20**, **Issue 5**, pp. 4-7—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Sep_Oct08.pdf#page=4*].

[4] The original nomenclature, AM-1, indicated that this was the first in the series of platforms with a morning (AM) local Equator crossing time, as opposed to the afternoon (PM) series, which later became known as Aqua. The original concept to achieve the long-term continuity needed for climate studies was to launch the exact same instrument complement on three platforms, launching five years apart. The later development of constellation flying techniques rendered this approach obsolete.

[5] The Earth Science Senior Review is NASA's once every three years process, since 2017 when all Earth Science instruments, operating beyond their original funded mission, submit proposals requesting funding for extended mission lifetimes.

[6] To read the feature article, visit *https://www.nasa.gov/feature/goddard/2018/nasa-s-terra-satellite-celebrates-100000-orbits*.

Hitomi Inada [JSS] discussed the status of the ASTER instrument. All telemetries for aliveness check and electrical performance trends are currently stable. Most of the life items (like VNIR pointing) have exceeded their planned life in orbit; however, their operational reliability and performance continue without anomalies and are expected to last the lifetime of the mission.

Kurt Thome [GSFC—*Terra Project Scientist*] presented certificates from their NASA Group Achievement Award to several Science Team Members. The recipients were being recognized for the 2017 Terra Lunar Deep Space Calibration maneuver, that involved a 360° pitch-over of Terra to observe the Moon. He also announced that he had just received notification that the Terra project was the recipient of the 2019 William Pecora Team Award, to be presented at the Pecora conference in Baltimore, MD on October 6, 2019. The AST is proud to be part of the Terra project—the longest operating satellite in NASA's Earth Observing System.

Applications Working Group

The Applications working group session featured presentations of science research projects. A summary is shown in **Table 1** on page 24.

Operations and Mission Planning Working Group

The Operations and Mission Planning working group oversees and reviews the acquisition programs executed by the ASTER scheduler. Because ASTER data acquisitions have to be scheduled every day (due to ASTER's average 8% duty cycle),[7] an automatic program was developed to select ~600 daily scenes from the possible 3000+ in the request archive. **Masaru Fujita** [JSS] discussed the status of acquisition scheduling. Urgent observations have the highest priority, and can be scheduled close to acquisition time. About 70 scenes are programmed per month, with over 95% acquisition success. Global Mapping data acquisitions are the lowest priority, and fill in the scenes for the daily quota. ASTER's goal is to acquire at least one cloud-free image each season for every place on Earth. Due to persistent cloud cover, success is typically ~85% after several years, at which time the program is restarted. The next restart is planned for summer 2019. Currently the effort has achieved about 45% success, so the program will continue, and will be reviewed again during the next team meeting. The thermal group submits areal requirements to acquire global nighttime coverage with the thermal bands. Several smaller acquisition programs focus on islands, volcanoes, glaciers, and cloudy areas. These programs are ongoing, and will be reviewed again next year to determine when to restart them. **Tetsui Tachikawa** [JSS] reviewed the status of the cloud avoidance algorithm. The scheduler incorporates cloud prediction values to eliminate possibly cloud-contaminated acquisitions. Application of the program continues to result in an ~10% increase in efficiency acquiring cloud-free or less-cloudy images.

[7] This rate is due to ASTER's allocation of 8 minutes of data acquisition per 99-minute orbit.

Data Products and Digital Elevation Model (DEM) Working Group

There is now an improved version of the Level-2 processing algorithms in place. For higher-level products (e.g., surface reflectance) a user can request that the input data be the terrain-corrected product (Level-1T) and that atmospheric correction be implemented using simultaneously acquired MODIS data products (e.g., water vapor profile). The next version of the software will implement a more accurate water vapor correction for the TIR data.

Most of the DEM discussion focused on the coming release of the Global Digital Elevation Model Version 3 (GDEM3) and the ASTER Water Body Dataset (ASTWBD). **Michael Abrams** showed the improvements resulting from Robert Crippen's [JPL] editing of the over 22,000 DEM tiles using his custom software. Almost all of the artifacts have been removed, including remnant cloud artifacts and those caused by use of low-quality USGS GMTED2010 data to fill

continued on page 25

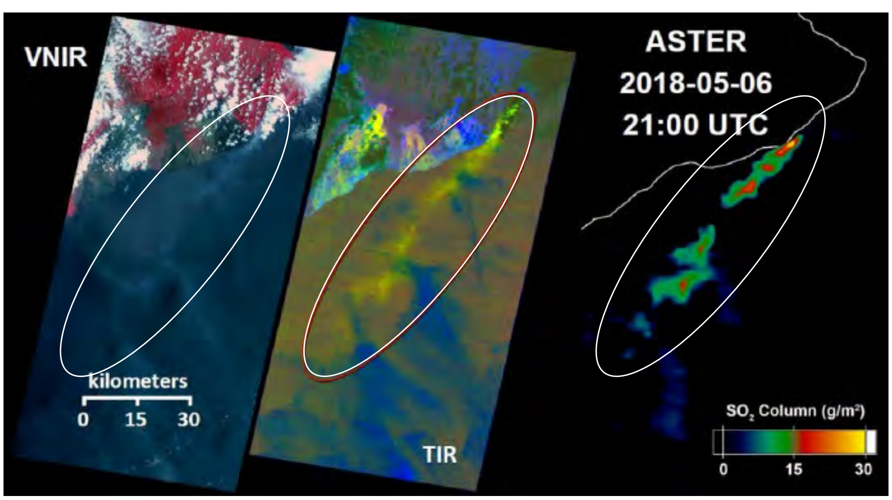

Figure 1. Sulfur dioxide (SO_2) retrieval [*right*] from ASTER TIR data obtained on May 6, 2018 over the Kilauea East Rift Zone eruption in Hawaii [*center*]. The VNIR image [*left*] is shown for comparison; notice that at VNIR wavelengths, the SO_2 plume, seen clearly in the TIR image, is indistinguishable from clouds. **Image credit:** Vincent Realmuto [JPL]

Table 1. Speakers, presentation topics, and summaries from the Applications working group.

Name [Affiliation]	**Topic**	**Summary**
Yasushi Yamaguchi [NU]	Characterizing urban sprawl	Described a *sprawl elasticity index*, derived from remote sensing data and population data, to characterize urban sprawl.
Michael Abrams [JPL]	Meeting presentations	Presented highlights from posters presented at the European Space Agency's Living Planet meeting, and at the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) Science Team meeting.*
Michael Ramsey [UP]	ASTER Urgent Request Program (URP)	Explained how the URP now uses the Middle InfraRed Observation of Volcanic Activity (MIROVA) algorithm, which is more sensitive than that which is used by the Moderate Resolution Imaging Spectroradiometer (MODIS), to trigger ASTER data acquisitions over volcanic hotspots.
Dave Pieri [JPL]	ASTER Volcano Archive (AVA)	Stated that the AVA is being ported to Amazon Web Services, with a more sophisticated graphical user interface. New sulfur dioxide (SO_2) and thermal anomaly detections will be available.
Truong Van Thinh [UT]	Forest mapping	Explained that using PALSAR-2** data, accuracy annual forest cover maps have been produced to help the government manage Vietnam's resources.
Vincent Realmuto [JPL]	Sulfur dioxide (SO_2) detection and mapping	Showed how SO_2 retrievals from ASTER, MODIS, and Visible Infrared Imaging Radiometer Suite (VIIRS) data were compared for the 2018 Hawaii eruption. Results were similar, despite large resolution differences—see **Figure 1**.
Michael Ramsey [UP]	ASTER volcanic ash library	Showed how laboratory TIR spectra of volcanic ash were applied to ASTER image data. Particle size distribution within plumes could be extracted from the ASTER TIR data.
Hiroyuki Miyazaki [UTs]	Building mapping	Explained how detailed building maps were produced for Sri Lanka, Rwanda, parts of Kenya, and Laos using ~0.5-m data from Google Earth.
Tomoaki Miura [UH]	Land surface dynamics	Described how using Himawari geostationary data, high-temporal-resolution data were combined with more traditional (e.g., MODIS) data to study land surface dynamics.
Yoshiee Ishii [IU]	Land cover classification	Showed how grade-added rough set classification method was applied to land cover classification. An improvement was found compared with traditional methods.
Hiroki Misuochi [AIST]	Deforestation mapping	Described the development of an automated deforestation mapping system using ASTER, Landsat, and Palsar-2 data.
Toru Kouyama [AIST]	Finding solar panels	Explained how deep learning algorithms have been used to find solar panels on rooftops and in fields using Landsat 8 images, and monitoring thermal anomalies with ASTER data.

* The ESA Living Planet meeting was held May 13-17, 2019, in Milan, Italy. The ECOSTRESS Science Team Meeting took place March 19-20, 2019, in Pasadena, CA; a related ECOSTRESS Workshop, held March 21, is summarized in the July–August 2019 issue of *The Earth Observer* [**Volume 31**, **Issue 4**, pp. 15-18—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Jul_Aug_2019_final_color_508_0.pdf#page=15*].

** PALSAR 2 stands for Phased Array type L-band Synthetic Aperture Radar; it flies on Japan's Advanced Land Observing Satellite-2, or DAIACHI-2, which launched in 2014.

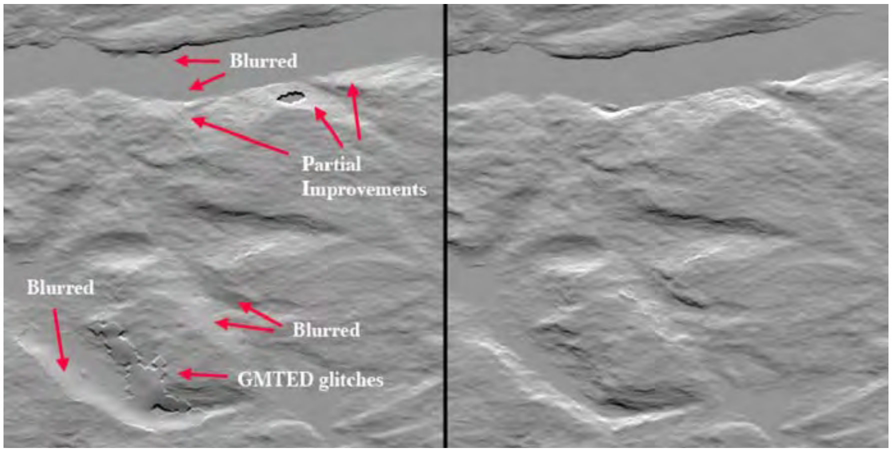

Figure 2. ASTER GDEM3 before [*left*] and after [*right*] editing to remove artifacts. **Image credit**: Robert Crippen [JPL]

voids—see **Figure 2**. The ASTWBD is a raster dataset, identifying ocean, lakes, and rivers, and also providing elevation values for the three different water bodies. This is a unique, global dataset that will be welcomed by the hydrology community. Both the Land Products Distributed Active Archive Center (LP DAAC) and JSS are ingesting the datasets into their distribution systems. A simultaneous release of GDEM3 and ASTWBD is planned for late July.

Chris Torbert [USGS] reviewed the status of the geometric performance of ASTER. Using the Landsat assessment system, thousands of ASTER scenes have been examined and compared with a library of ground control points. The geometric accuracy of the ASTER scenes continues to fall within mission requirements, indicating there are no problems either with the processing system, spacecraft, or instrument performance.

Temperature-Emissivity Working Group

The Temperature-Emissivity working group is concerned with ASTER's kinetic temperature and emissivity products. They discussed applications of these products, and reviewed the status of the nighttime TIR global map program. Based on **Masaru Fujita's** [JSS] assessment of the map's progress, the working group recommended restarting the program, as the one currently running has achieved 85% success.

A summary of presentations delivered at the working group is shown in **Table 2**.

Table 2. Speakers, presentation topics, and summaries from the Temperature-Emissivity Working Group.

Speaker [Affiliation]	**Topic**	**Summary**
Yudai Mizoguchi [IU]	Classification of Lakes	Showed that by using the satellite-based lake and reservoir temperature database in Japan, 228 of 1003 water bodies were classified—see **Figure 3**.
Michael Ramsey [UP]	Status of the Miniature Multispectral Thermal (MMT) TIR camera	Showed how UP has developed a portable multi-spectral TIR camera. It is calibrated for low and high temperature sources.
Yuji Yoike [IU]	Ice thickness estimation	Explained how MODIS data were used to estimate ice thickness of Lake Saroma, Japan; validation was measured with ice cores.
James Thompson [UP]	Evaluation of TES code	Discussed development of a scaling factor to minimize effect on low contrast spectra when determining emissivity from ASTER data.
Yuta Oguri [IU]	Emitted power of industrial zone	Showed measurements of the intensity of radiant energy for Kashima Coastal Industrial Zone, Japan, from 30 ASTER night TIR scenes.
Jigjidsuren Batbaatar [UW]	Mapping the zero curtain duration	Showed how using a time series of MODIS land surface temperature data, it was possible to distinguish between seasonal ground ice and permafrost.
Hideyuki Tonooka [IU]	Status of cloud assessment and nighttime TIR map	Explained that based on detailed analysis of cloud cover of the entire archive of nighttime TIR scenes, 89% of scenes have been observed at least once.

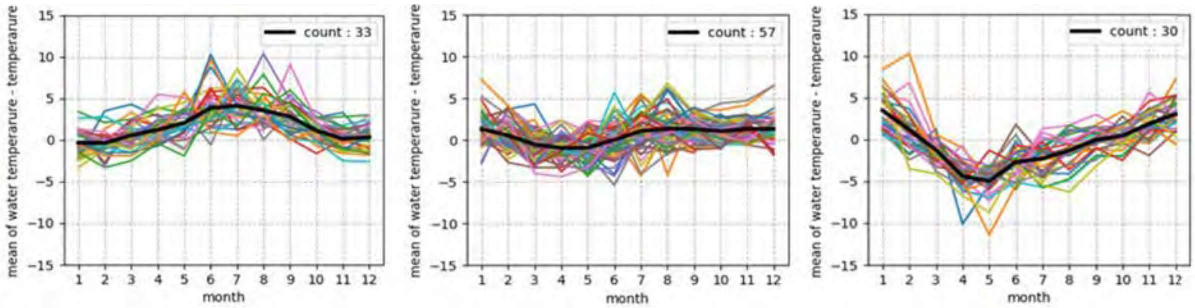

Figure 3. Classification of 120 Japanese lakes based on differences in seasonal change of water temperature minus air temperature. The three graphs show data for lakes with: shallow depth, low elevation, abundant inflow, high summer water temperature [*left*]; shallow depth, middle elevation, weak snowmelt, almost uniform temperature difference all year [*center*]; and deep depth, high elevation, large snow runoff, water warmer than air in winter [*right*]. The back curve is average of individual lake curves, shown in various colors. **Image credit:** Yudai Mizoguchi [IU]

Calibration/Validation Working Group

The Calibration/Validation working group is responsible for monitoring the radiometric performance of ASTER's VNIR and TIR instruments. For the VNIR, calibration and validation are performed by analysis of onboard calibration lamps and measurements of pseudo-invariant ground targets during field campaigns. Since the last ASTM, **Satoru Yamamoto** [JSS] reported that seven VNIR onboard calibrations were performed. There have been no significant changes in any of the data trends, including dark current response, lamp calibration data, output and temperature of the photodiodes, and signal-to-noise values. For the TIR, an onboard blackbody provides several measured temperatures to evaluate instrument response. Seven TIR calibrations were performed. There was no significant change for all measured data trends. Calibration accuracy is within the mission specifications of 0.5% for ground temperatures between 300 K and 320 K, and within 1% for temperatures greater than 340 K.

There were six reports on calibration/validation field campaigns: two for the VNIR and three for the TIR; and one VNIR calibration report using the Lunar Calibration experiment. **Satoshi Tsuchida** [AIST] and his team went to Railroad Valley, NV, four times in 2018. Weather conditions were marginal, so the results of the campaign were of questionable value. Seven more measurement campaigns are planned for 2019. **Hirokazu Yamamoto** [AIST] matched up ASTER data over the Committee on Earth Observation from Space (CEOS) Radiometric Calibration Network (RadCalNet) sites in the U.S., France, China, and Namibia. Larger errors were found for the ASTER acquisitions when the instrument pointed 8.5° off-nadir. **Toru Kouyama** [AIST] summarized the radiometric results from the August 2017 Terra Deep Space Lunar Calibration Maneuver, and compared them with a similar maneuver from 2003—see **Figure 4.** The results provide strong support for constraining ASTER VNIR degradation curves and establishing and updating the calibration coefficients. **Satoshi Tsuchida** [AIST] led a discussion of possible methods for the next update of the radiometric calibration coefficients. The favored method is to combine the results from the Lunar Calibration Maneuver and vicarious results from field campaigns. After three months the committee will report the results of exercising this option.

There were three reports on TIR field campaigns. A team led by **Soushi Kato** [RESTEC] visited three sites in Nevada. The brightness temperature difference between vicarious top-of-atmosphere values and ASTER standard product values was within 1 °C for Band 14. Other field campaigns found that Band 14

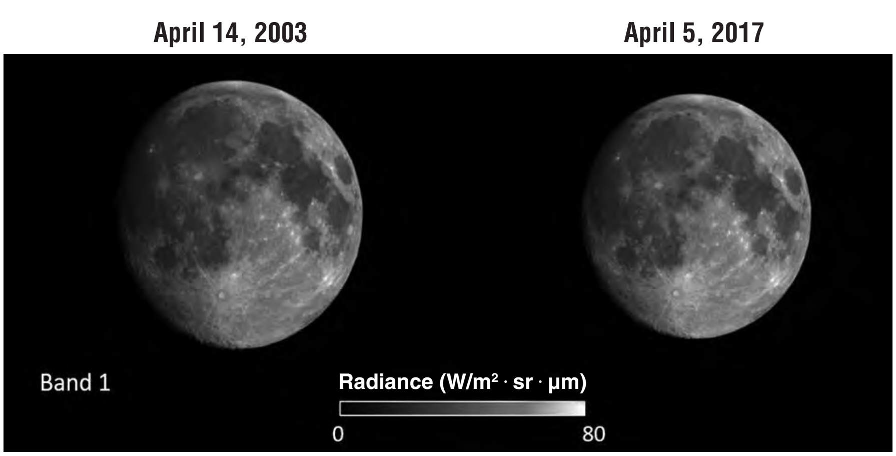

Figure 4. Comparison of ASTER Band 1 images of the Moon obtained during the two Terra Deep Space Lunar Calibration Maneuvers on August 14, 2003 [*left*] and August 5, 2017 [*right*]. Comparison of data between the two maneuvers has allowed for more accurate calibration of ASTER data. **Image credit**: Toru Kouyama [AIST]

met specifications. **Hideyuki Tonooka** [IU] occupied three sites in Nevada and two sites in Japan to conduct his validation activities. While four of the experiments were successful, clouds contaminated the other campaigns. He made measurements both during the day and at night. Results indicate that the onboard calibration is keeping the design accuracy of 1 K. **Michael Abrams** reported on the past year's vicarious calibration measurements at the instrumented buoys on Lake Tahoe and Salton Sea, CA. Comparison between the buoy measurements and ASTER data products indicated that there has been no noticeable change in the TIR instrument performance the past twelve months.

Closing Plenary Session: Meeting Summary

The chairpersons of each of the working groups presented summaries of presentations and discussions of their sessions. The overall consensus of participants was that ASTER continues to perform nominally, with no change since the 2018 meeting. Updates of the calibration coefficients will take place in 2020, incorporating results from onboard calibration sources, the 2017 Terra Deep Space Lunar Calibration Maneuver, and field-based validation measurements. The GDEM Version 3 and the new ASTWBD will be released in July 2019. The AST anticipates that NASA and METI will sign the Diplomatic Note extending joint operation of the ASTER project for an additional seven years starting October, 2019. The next meeting will be held June 1-3, 2020, at the same venue in Tokyo.

Acknowledgment

Work by the lead author (**Michael Abrams**) was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA.

NASA Lights the Way at AGU Fall Meeting

As the American Geophysical Union (AGU) marks its Centennial in 2019, the AGU Fall Meeting returns to San Francisco, CA, December 9-13, 2019, after a two-year hiatus due to renovations at the Moscone Center.

Please make plans to visit the NASA booth (#535) in the exhibit hall, opening on Monday, December 9, and continuing through Friday, December 13.

The theme for this year's NASA exhibit is *NASA Lights the Way*. At the exhibit, visitors can learn how NASA "lights the way" and expands the frontiers of science through investigations of Earth science, heliophysics, planetary science, and astrophysics. The focal point of the exhibit experience will be the nine-screen Hyperwall, where scientists will share science stories throughout the week. A wide range of science demonstrations, printed material, and tutorials on various data tools and services will also be available.

A daily agenda will be posted on the Earth Observing System Project Science Office website—*http://eospso.nasa.gov*—in early December.

We hope to see you in San Francisco!

A NASA science presentation using the dynamic Hyperwall display during the 2018 AGU Fall Meeting. **Photo credit:** NASA

Summary of the Spring 2019 NASA Land-Cover and Land-Use Change Science Team Meeting

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Introduction

The Spring 2019 NASA Land-Cover and Land-Use Change (LCLUC) Science Team Meeting was held April 9-11, 2019, at the Hilton Washington in Rockville, MD. The meeting consisted of presentations on LCLUC activities in Southeast Asia, the Caucasus region, and the synthesis projects—discussed on page 31 of this article. There was a poster session on day one, which consisted of presentations from recent LCLUC-funded projects. It also included the presentations from LCLUC-themed projects funded primarily through the NASA Interdisciplinary Science, Carbon Cycle, Graduate Student, and New Investigator Programs. The three-day event was organized into eleven sessions, which are summarized here. A total of 134 participants attended the meeting. The meeting presentations and posters can be accessed at http://*lcluc.umd.edu/meetings/2019-nasa-lcluc-spring-science-team-meeting*.

Opening Plenary

The meeting began with welcome remarks from **Garik Gutman** [NASA Headquarters (HQ)—*LCLUC Program Manager*], who shared new program developments and achievements. Gutman mentioned that over 300 projects have been funded since the program's inception in 1995. He said that all LCLUC proposals are required to have a socioeconomic component, except for special thematic calls, such as Multi-Source Land Imaging (MuSLI), which is purely remote-sensing focused. He showcased the program's linkages within NASA's Earth Science Division (ESD) and emphasized that although the LCLUC program is part of the Carbon Cycle and Ecosystems research focus areas, the LCLUC theme runs across other ESD programs, such as Terrestrial Ecology, Biodiversity, and Applied Sciences. Additionally, the LCLUC program interacts with other research focus areas, mainly with Water and Energy Cycle and Atmospheric Composition. Gutman also highlighted the program's external linkages nationally, such as with the U.S. Geological Survey (USGS) and the U.S. Agency for International Development (USAID), and internationally, with Global Observations for Forest Cover and Land Cover Dynamics (GOFC-GOLD), the Committee on Earth Observation Satellites (CEOS), the Japanese National Institute for Environmental Studies (NIES), the European Space Agency (ESA), and the European Association of Remote Sensing Laboratories (EARSeL). Gutman showcased the new Mapper product on the LCLUC website (*https://lcluc.umd.edu*). The Mapper provides the geographical distribution of all principal investigators as well as the project team members for the current and the past LCLUC projects. It also shows the geographic distribution of study areas of the LCLUC projects, which helps to see the work done by different LCLUC projects in the selected area of interest.

Chris Justice [University of Maryland, College Park (UMD)—*LCLUC Program Scientist*] outlined the meeting agenda. Justice stated that land-use/land-change science is central to a number of international policy issues, and that there is an opportunity for LCLUC researchers to address the policy questions. Justice mentioned that the success of the recent LCLUC regional initiatives, e.g., the Northern Eurasian Earth Science Partnership Initiative (NEESPI) and the South/Southeast Asia Research Initiative (SARI), have contributed to the growing reputation of the program globally. He noted that a number of long-standing missions have reached or are reaching milestone anniversaries, such as 40 years for AVHRR[1] and 20 years for MODIS,[2] and that addressing long-term data continuity is essential. He stated that the LCLUC community is a major science user of moderate-resolution sensor data (including Landsat and the European Union's Copernicus Sentinel-2[3] data), and that there is a need to strengthen relationships between NASA's LCLUC program and the USGS's Landsat Science Team. Justice also highlighted current and near-term Earth observation missions relevant to LCLUC, e.g., NASA's Global Ecosystem Dynamics Investigation (GEDI) and ECOsystem Spaceborne Thermal Radiometer Experiment on Space

[1] AVHRR stands for Advanced Very High-Resolution Radiometer, which flew on a series of NASA, NOAA, and international platforms over the past 40 years. The first AVHRR instrument was launched on the Television Infrared Observation Satellite-N (TIROS-N) in October 1978; the last AVHRR instrument was launched just over 40 years later on the European Metop C satellite in November 2018.
[2] MODIS stands for Moderate Resolution Imaging Spectroradiometer, which flies on NASA's Terra and Aqua platforms. Terra will celebrate the twentieth anniversary of its launch in December 2019; Aqua was launched in May 2002.
[3] Sentinel-2 is an Earth observation mission from the EU Copernicus Programme that systematically acquires optical imagery at high spatial resolution (10 m to 60 m) over land and coastal waters. The mission is a constellation with two twin satellites (Sentinel-2A and Sentinel-2B).

Station (ECOSTRESS) missions,[4] and the joint NASA-Indian Space Research Organization (ISRO) Synthetic Aperture Radar mission [NISAR].[5] He also mentioned about a number of private-sector companies (e.g., DigitalGlobe, Planet (previously Planet Labs), SPIRE) that are currently working on developing satellite constellations. He stated that it would be beneficial for the LCLUC community to identify the derived-product needs from the current and new NASA missions.

Jack Kaye [NASA HQ—*Associate Director for Research for the ESD*] provided NASA's Earth Science updates. He acknowledged the contribution of the LCLUC program to the Earth science research community, especially with its global agenda involving regional scientists. Kaye stressed the importance of these studies, noting that it is quite difficult to understand and interpret LCLUC without the human component. The need to address such difficulties is the basis for requiring socioeconomic analysis in LCLUC proposals. He presented the current and future ESD interests and activities and talked about fellowship opportunities and education programs. Kaye also encouraged LCLUC researchers to participate in applications-related solicitations.

Evaluation of High-Resolution Data for LCLUC Applications

This session focused on evaluating the use of very-high-resolution (VHR) data for LCLUC Science. Thirty-four researchers were chosen by NASA HQ to participate in a pilot study for one year from November 1, 2018 through October 31, 2019, to understand how VHR data can advance LCLUC science.

[4] Both GEDI and ECOSTRESS are deployed on the Japanese Experiment Module's Exposed Facility onboard the International Space Station.
[5] NISAR is currently planned for launch in 2021.

Garik Gutman chaired the session. He explained that NASA is assessing the value of VHR data from two commercial data vendors—Planet and Digital Globe. The goal of the pilot studies is to understand how VHR data advance the science in ways that cannot be accomplished with existing NASA assets and how they can assist in strategic decision making for future NASA engagement in commercial data buys.

Krishna Vadrevu [NASA's Marshall Space Flight Center (MSFC)] helped coordinate these thirty-four different VHR pilot studies by creating web-based forms for consistent evaluation of the data across three stages (initial, mid-term, and final). The use of VHR data is being evaluated by different PI's such as on forest monitoring, carbon-footprint analysis, crop-area and productivity estimation, canopy chlorophyll content estimation, island studies, and burnt-area mapping in agricultural landscapes. The final results from the PI's are due by October 31, 2019.

LCLUC in Southeast Asia

This session focused on the SARI projects, with presentations from six Principal Investigators (PIs).

Jefferson Fox [East-West Centre, Hawaii] presented results on the agrarian transition in mainland Southeast Asia, showing changes in rice farming from 1995 to 2018. He mentioned that rice production per hectare has more than doubled while the average size of farms decreased considerably, and the average age of farmers increased to over 50 over the past two decades. Also, farmers now prefer crop diversification, with double and triple cropping systems (i.e., two or three crops being rotated throughout the year).

Participants at the NASA LCLUC Spring 2019 Science Team Meeting. **Photo credit:** Jack O' Bannon [UMD]

Jessica McCarty [Miami University, Ohio] presented her work on quantifying LCLUC and modeling its future trajectory of LCLUC in Southern Vietnam through the lenses of conflict, religion, and politics. MODIS data, combined with VHR datasets from Planet, are being used to map forest, agriculture, and urban change from 1985 to the present.

Prasad Bandaru [UMD] presented his results on the effects of agricultural land-use change in Central and Northeast Thailand on biomass emissions, soil quality, and rural livelihoods. He explained that burning crop residues has a significant impact on greenhouse gas emissions as well as on soil quality, which in turn impacts long-term agriculture productivity.

Son Nghiem [NASA/Jet Propulsion Laboratory (JPL)] provided details on the dense-sampling approach using microwave scatterometer data from NASA's Quick Scatterometer (QuikSCAT) mission to characterize urban built-up volume and extent at a 1-km (~0.6-mi) resolution. This study aims to quantitatively document the current status and rate of change of land cover and land use and how trajectories of these changes are linked to population and demographic transitions for the Southeast Asian countries of Vietnam, Cambodia, and Laos.

Jiaquo Qi [Michigan State University] showed the impact of dams in the Lower Mekong River Basin. He noted that the number of dams is increasing globally, which has significant implications on the water-energy-food nexus and socioeconomic consequences; hence, there is high need to monitor dams through remote sensing.

Laixiang Sun and **Julie Silva** [both at UMD] presented their research on quantifying corruption in land-system governance in Indonesia and the impact of oil-palm expansion on deforestation. Sun explained that oil palm is Indonesia's dominant estate crop and that demand for oil products is the significant driver for its expansion, which is leading to deforestation and a drop in carbon storage capacity and forest biodiversity.

Poster Presentations

A poster session closed out the first day of the meeting. It was preceded by lightning introductions to the posters, which spanned a wide range of LCLUC topics including agriculture, urban health, forest studies, and ecosystem monitoring. A total of 30 posters were presented, including an invited presentation by **Ioannis Manakos** [The Centre for Research and Technology, Greece] who highlighted ECOPOTENTIAL achievements in LCLUC products generation and online monitoring data services for ecosystem indicators. ECOPOTENTIAL is a large European-funded project that focuses its activities on a targeted set of internationally recognized Protected Areas, blending Earth Observations from remote sensing and field measurements, data analysis, and modeling of current and future ecosystem conditions and services.

International Linkages and Capacity Building in Southeast Asia

Krishna Vadrevu began the session with a discussion about the origin of the SARI program and gave highlights from the last four years, explaining that 18 projects have been funded under SARI and that there have been more than 100 institutional collaborations. Based on SARI outputs, a book and over 150 research papers have been published in 9 different journal special issues. The book titled *Land-Atmospheric Research applications in South and Southeast Asia* (*https://www.springer.com/gp/book/9783319674735*) published by Springer is one of the top downloaded books within four months of its publication during 2018. Vadrevu stated that the SARI team will continue strengthening its research and capacity building activities in the coming years.

Nancy Searby [NASA HQ] discussed the training and education components of NASA's Applied Sciences Program being implemented through the Applied Remote Sensing Training (ARSET), SERVIR, and DEVELOP programs.[6] Searby stressed that SERVIR is helping developing countries use information provided by Earth-observing satellites and geospatial technologies to manage climate risks and land use. **Pariwate Varnakovida** [King Mongkutt's University, Thailand] described capacity-building activities in Thailand, including those of the Geo-Informatics and Space Technology Development Agency (GISTDA), the Thai space agency. Following the formal presentations, **Chris Justice** and **Krishna Vadrevu** led an open discussion on the future directions of SARI and capacity-building activities in the region.

Synthesis Projects over the Globe

The goal of the LCLUC synthesis projects is to harmonize findings to develop a broader regional understanding of relevant phenomena and to strengthen the theoretical underpinnings of LCLUC science. Synthesis projects are currently in their second year. The PIs discussed their respective projects' progress, data collections, model building and testing, and issues faced to date.

Stephen Walsh presented his work on LCLUC in island ecosystems, looking at socioeconomic, demographic, tourism, community infrastructure, geographic, and biophysical drivers of LCLUC and patterns of change over the years using satellite imagery, analyses, and derived-products for global islands. His observations indicate that population and tourism are increasing across the islands at a considerable rate and causing undue harm to ecosystems.

[6] ARSET, SERVIR, and DEVELOP are components of NASA's Applied Sciences Program. Links to each component are found at *https://appliedsciences.nasa.gov/Program-Elements*. Note that SERVIR and DEVELOP are not acronyms. SERVIR means "to serve" in Spanish.

Valerie Thomas [Virginia Tech] reported on a synthesis project that addresses land-management processes and their influence on land-use transitions in the Southeast U.S.

Dan Brown [University of Washington] presented information on the synthesis of large-scale transactions as drivers of land-cover change in Sub-Saharan Africa. He stated that over the past decade an unprecedented global boom in land transactions, commonly referred to as *land grabbing* has occurred globally. Driven by volatility in agriculture commodity prices, interest in biofuel production, and the eagerness of governments to pursue economic development, transitional and domestic investors are increasingly acquiring land resulting in displacement of locals and their livelihoods.

Nicholas Magliocca [University of Alabama] explained archetypical pathways of direct and indirect land-use change caused by economic land concessions (ELC) in Cambodia. Concession lands are leased by the Cambodian government to domestic and foreign investors for various functions, including agribusiness and redistribution of land to the landless and land-poor, timber production, and other uses. He mentioned that 2.3-M hectares of land are within the boundaries of ELC and contribution of ELC to forest loss rose from 12.1% in 2001 to 27.0% in 2012. Hence land concession is one of the major drivers of deforestation in Cambodia.

LCLUC in Northern Eurasia

Pavel Groisman [National Oceanic and Atmospheric Administration] discussed progress by the Northern Eurasia Future Initiative (NEFI) and the role of LCLUC's Caucasus projects. The NEFI has been designed as an essential continuation of NEESPI, which was launched in 2004. Around 750 scientists, 80 PhDs, and over 200 institutions have been involved in NEFI-NEESPI, with 170 projects in 30 countries and over 1500 papers and 40 books published to date.

Pontus Olofsson [Boston University] delivered a presentation on analysis of land change in Georgia, explaining the drivers and patterns of change and carbon dynamics in the region over last three decades.

Volker Radeloff [University of Wisconsin, Madison] described long-term degradation in the Caucasus region, with data obtained by mapping forest and grassland degradation across the Caucasus from 1985 to 2015 with no major LCLUC, except for some agricultural land abandonment and recultivation.

Giorgos Mountrakis [State University of New York, Syracuse] presented information on the interacting effects of sociopolitical and environmental factors on rangeland dynamics in the Altai Mountains transboundary zone.

Kirsten de Beurs [University of Oklahoma] gave a presentation on her work to investigate trends in land use in the Caucasus between 1984 and 2019, focusing specifically on the change in agriculture technique from rain-fed to irrigation-supplied, forest fragmentation, and changes in characteristics and extent of open surface water bodies, in order to examine the implications of these changes for the population's vulnerability to reemergence of vector-borne diseases such as malaria.

Multi-Source Land Imaging (MuSLI)

The Multi-Source Land Imaging (MuSLI) component of the LCLUC Program aims to integrate Landsat and Sentinel-1 and -2 to generate continental-to-global-scale products (Type I) and regional prototype products (Type II). **Jeff Masek** [GSFC—*MuSLI Project Scientist*] led the session with updates on MuSLI and the Harmonized Landsat–Sentinel-2 (HLS) project. Masek stated that annual total output of HLS is around 120 TB—considerably less than upcoming NISAR data output, which is expected to be ~85 TB per day. Initially HLS was processed via NASA's Ames Research Center's NASA Earth Exchange (NEX) computing cluster, but beginning with Version 1.4, HLS has migrated to Amazon Web Services (AWS) via NASA's Earth Sciences Technology Office (ESTO), and the AIST Managed Cloud Environment [AMCE].

Christopher Crawford [USGS Earth Resources Observation and Science (EROS) Center] provided updates on USGS Landsat-related science. He informed the group that the USGS–NASA Landsat Science team is in the second year of their five-year term (2018–2023) and their priority is to characterize the science requirements for future Landsat missions. He stated that Landsat 9 activities are progressing quickly, with a launch planned for December 2020.

After Crawford's presentation, Masek led a discussion during which the eight MuSLI investigators gave progress updates on their research. Included among these were three continental-scale (Type I) projects, focusing on operational land-surface phenology, burnt areas, and the circumpolar albedo of Northern lands. In addition, there were five regional-scale (Type II) projects, which dealt with various topics including canopy chlorophyll content to assess vegetation function and productivity; land-surface-temperature products for urban environments, monitoring abandoned agricultural land, fallow fields, and grasslands; and crop-yield assessment and mapping using multisource satellite data.

Glynn Hulley [JPL] presented the high spatio-temporal resolution land surface temperature product generated by combining ECOSTRESS thermal data and Landsat 8 visible shortwave infrared data in a thermal sharpening model. He showed an example of data obtained over the area around Los Angeles, CA—see top image in **Figure**. Hulley then showed a map of the *heat-vulnerability index* around Los Angeles—bottom image in Figure—which is derived by combining the high spatial resolution surface temperatures with socio-demographic variables (e.g., poverty, income, population density, age) using a heat vulnerability index (HVI) model.

Masek concluded the session by giving closing remarks outlining future directions for the MuSLI and Landsat programs.

Strengthening Linkages between the NASA LP DAAC and LCLUC Program

The Land Processes Distributed Active Archive Center (LP DAAC) is one of several discipline-specific data centers of NASA's Earth Observing System Data and Information System (EOSDIS). It is resident at the USGS EROS Center in Sioux Falls, SD. The LP DAAC processes, archives, and distributes land data products to hundreds of thousands of users in the Earth science community.

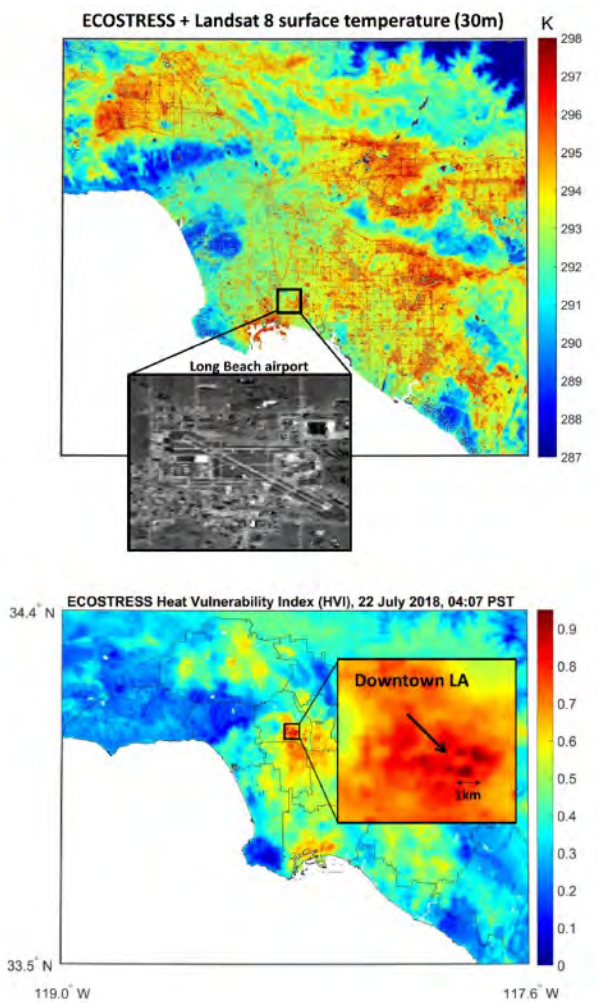

Figure. The top image shows high spatio-temporal resolution land surface temperature product for Los Angeles, CA, generated by combining ECOSTRESS and Landsat 8 through the LCLUC MuSLI Project. The high spatial resolution (30 m, or ~98 ft) of the data allows fine scale temperature details (e.g., the runway of Long Beach airport, which is shown in the Inset image) to be delineated in order to map hotspots and infer heat vulnerability in cities. The bottom image shows a map of the heat vulnerability index, which is created by combining high spatial resolution surface temperatures with socio-demographic variables in a *heat vulnerability index* (HVI) model. Heat-related vulnerability can be mapped at fine scale and used by city planners to implement cooling technologies and green infrastructure to curb future warming, as shown in the close-up image of downtown Los Angeles. **Image credit:** Glenn Hulley [JPL]

Chris Doescher [USGS—*LP DAAC Project Manager*] described the LP DAAC and the land products that are universally accessible. Such data are used to support ongoing monitoring of Earth's land cover and to facilitate interdisciplinary research, education, and decision-making. Since the LCLUC community is a major user of LP DAAC services, Doescher stressed the need to strengthen the connections between the USGS and LCLUC programs.

Discussion of Future Directions for the LCLUC ST

Chris Justice summarized major points from the meeting and gave talking points on future directions for the LCLUC program. Justice emphasized interdisciplinary science, telecoupling frameworks, and strengthening land-change science in future initiatives. Discussion involved feedback from the participants on various topics including the evaluation of VHR data and interactions with commercial vendors, the planned young scientist initiative,[7] increasing the visibility of the program through synthesis studies, regional workshops, the program website, and peer-reviewed publications.

Garik Gutman adjourned the meeting by delivering wrap-up statements, strongly encouraging participants to contribute to the program through webinars, social media, and by sharing their publications, news, and datasets on the LCLUC website. Gutman encouraged PIs to make their data and products available to the broader community. He also mentioned several upcoming LCLUC-related international meetings.

Conclusion

The LCLUC Science Team Meeting met its objective of bringing together LCLUC researchers from across the U.S. to report on research progress, strengthen partnerships and collaborations, highlight ongoing programmatic developments, and address LCLUC community concerns.

There was a LCLUC–SARI regional Science Team Meeting in July 2019, in Johor Bahru, Malaysia; the next LCLUC Science Team Meeting will be in April 2020. NASA LCLUC community members are encouraged to visit the website (*lcluc.umd.edu*) regularly for program updates, and to follow the program on Twitter (@LCLUCProgram) and Facebook. ■

[7] The LCLUC Program encourages young scientists to get involved in integrated research combining satellite remote sensing, land-use change, and the social science needed to understand the processes of change. Recognizing that it can be hard for young scientists to compete with more experienced researchers, the LCLUC young scientist initiative is targeted at recently completed PhD researchers (<5 years).

Summary of the USFS–NASA Joint Applications Workshop on Satellite Data for Natural Resource Management

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Introduction

A joint U.S. Forest Service (USFS)–NASA Applications Workshop took place April 29–May 2, 2019. The USFS hosted the meeting at its Geospatial Technology and Applications Center (GTAC) in Salt Lake City, UT. This unique collaborative venture bought together representatives from USFS, multiple NASA missions and projects, several NASA data centers, and other relevant entities (detailed later). The workshop provided an opportunity to increase awareness of the application of Earth observation (EO) data in support of land and natural resource management goals.

The three-day workshop served as a forum to share and demonstrate the capabilities of NASA's data products, as well as to foster connections and strengthen partnerships between the USFS, NASA, and other partners. In support of these goals, the meeting objectives were to:

- provide an overview of NASA's missions and projects, data, and tools supporting natural resource management;
- share and prioritize USFS operational needs with NASA;
- identify opportunities for collaboration; and
- expand USFS awareness of NASA's EO data sources and tools and explore ways to advance information delivery.

To address these objectives, the meeting agenda included a mix of informative sessions punctuated by breakout sessions, hands-on data tutorials, and a poster session. The summary that follows begins with a few words on the motivation for the workshop followed by a summary of the content. The full agenda and presentations can be found at the workshop website, *https://www.regonline.com/builder/site/default.aspx?EventID=2536184*.

Motivation for the Workshop

The USFS is facing natural resource management challenges exacerbated by climate change. From 1995 to 2015, the portion of the USFS annual budget devoted to fire preparedness and suppression programs increased from 16% to over 50%.[1] The average area burned by wildfires each year in the U.S. has nearly doubled since the 1990s, driven largely by declines in summer precipitation in western states. As more and more of the agency's resources are spent each year to provide the firefighters, aircraft, and other assets necessary to protect lives, property, and natural resources from catastrophic wildfires, fewer and fewer funds and resources are available to support other agency work. In addition to wildfire impacts, hundreds of millions of trees have died in the twenty-first century in the U.S. from unprecedented droughts and insect outbreaks. Recently, U.S. Department of Agriculture (USDA) designated rangelands in 25 counties in New Mexico and Arizona as primary natural disaster areas from persistent drought.

With fewer "boots on the ground," the use of remote sensing is an increasingly appealing option for gathering the key information needed to inform land-management decisions. Remote sensing and geographic information system (GIS) technologies can provide USFS natural resource managers a more cost-effective approach to monitoring natural resources on national forest lands, helping to inform key sustainable management decisions, and delivering benefits to the public.

Workshop Structure

NASA and USFS worked together to plan the workshop, with logistical support provided by NASA's Soil Moisture Active Passive (SMAP) mission and, in part, by the Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) mission, with in-kind support from USFS. **Chalita Forgotson** [Science Systems and Applications Inc. (SSAI)/NASA's Goddard Space Flight Center (GSFC)—*SMAP Research Scientist* and *Applications Lead*] and **Erik Johnson** [USFS—*Program Analyst, Office of Sustainability and Climate*] co-led workshop planning and organization efforts with support from a planning committee composed of participants from USFS, NASA's GSFC, NASA/Jet Propulsion Laboratory (JPL), National Snow and Ice Data Center (NSIDC), Oak Ridge National Laboratory (ORNL),

[1] To learn more, visit *https://www.fs.fed.us/sites/default/files/2015-Fire-Budget-Report.pdf*.

Alaska Satellite Facility (ASF), U.S. Geological Survey (USGS), and Boise State University.

Four of NASA's Earth Science satellite missions were represented at the workshop: SMAP; the joint NASA-Indian Space Research Organisation (ISRO) Synthetic Aperture Radar [NISAR]; ICESat-2; and the Global Ecosystem Dynamics Investigation (GEDI). NASA's Carbon Monitoring System (CMS) was also represented.

The workshop focused on four key research areas that are relevant for USFS management needs which can feasibly be addressed with a suite of EO data products and tools. The areas were:

- **Soil moisture and hydrology**. Topics included soil moisture dynamics, soil productivity and erosion, inventory and condition of wetlands, riparian areas, and groundwater-dependent ecosystems, aquatic habitat suitability, and land cover and hydrological change and vulnerability.
- **Vegetation condition**. Functional areas covered included vegetation structure and function, silviculture, rangeland management, fire and fuels, wildlife habitat, forest health, and carbon monitoring.
- **Emissions and flux**. Foci in this area included fluxes and emissions of aerosols and greenhouse gases (GHGs), and carbon flux.
- **Detecting, assessing, and monitoring ecosystem vulnerabilities**. These topics arise due to changing environmental conditions, such as climate change and other abiotic stressors.

An additional category of data and tools (called *knowledge synthesis*) focused on developing integrated decision-support tools e.g., to address the need to prioritize restoration projects with positive carbon benefits), supported data formats, cloud computing (e.g., big data handling), integration (mission, tools), and technology transfer to operational organizations (e.g., USFS—for this workshop, USGS, or the National Oceanic and Atmospheric Administration (NOAA).

Overview of USFS Management Goals and Information Needs

Everett Hinkley [USFS—*National Remote Sensing Program Manager*] welcomed attendees and provided a brief overview of the workshop, emphasizing that the goals were to identify gaps between existing NASA capabilities and USFS data and information needs and ways to close those gaps.

Cynthia West [USFS—*Director of Office of Sustainability and Climate*] emphasized the impacts of climate change on water supply and forest health, resulting in new management challenges arising from prolonged droughts and more expansive wildfires. She highlighted that forest managers need to be able to: detect change in forest cover, to guide policies and practices; detect changes in forest soil moisture, to guide restoration decisions; develop an early warning system for drought stress, to prioritize treatments; detect changes in snowpack, to guide annual water management and adaptation practices; monitor streamflow, to guide water management; and measure changes in range productivity, to guide herd and range allotment. At the end of her presentation, West illustrated the gap between research and operational applications at the USFS—see **Figure 1.** The graphic demonstrates a potential path for NASA and USFS to work together in bringing more of NASA's research-level capabilities to operation at the USFS, with USFS Research and Development playing an important *technology translator* role, as referenced throughout the workshop.

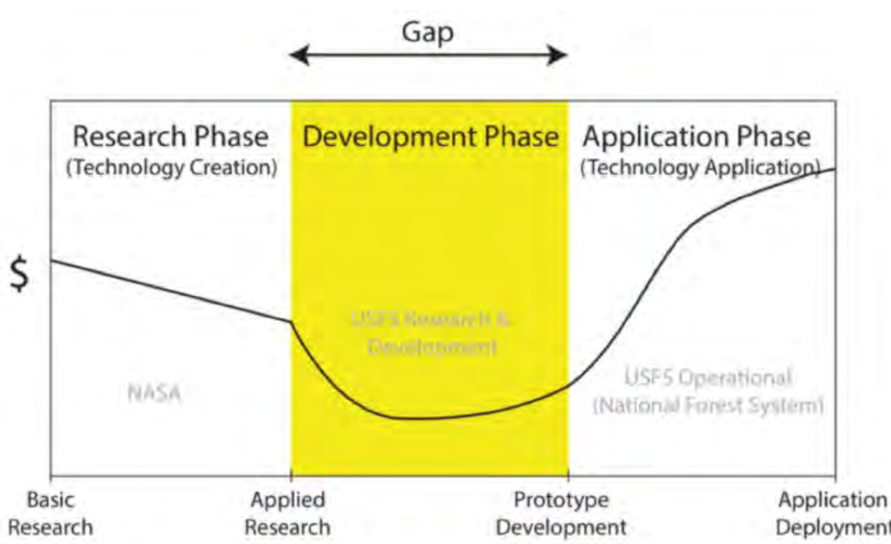

Figure 1. This figure illustrates the timeline of technology transfer, from research to operations, and the funding typically available during each stage. Funding opportunities are more widely available during the Research Phase, but decline during the Development Phase, then tend to rise again during the Application Phase. Many technologies, however, stall in this "gap" and fail to reach the Application Phase. Hence, this area of the timeline is sometimes referred to as "the Valley of Death"—e.g., *https://www.nap.edu/read/10658/chapter/4.* **Image credit:** Cynthia West

Following West's presentation, USFS managers and researchers outlined agency land management goals and information needs; current applications of EO data; and technical and systemic challenges affecting broader adoption of operational EO data applications related to a variety of topics. The presentations topics are summarized in **Table 1,** below.

The information presented made it clear that monitoring activities and management decisions take place across a range of spatial scales, from the project (single-hectare scale) and watershed level to the regional and national level. While USFS has historically relied heavily on *in situ* measurements to inform decision making, EO data are increasingly capable of providing information at spatial and temporal scales that would otherwise be too costly or difficult to collect. However, there are challenges around integrating EO data into existing decision-support systems, including spatial and temporal resolutions; data latency,[2] including the need to balance the time it takes to adopt EO data with mission lifetimes; users' awareness and understanding of EO data; and users' technical capabilities to process EO data.

Reports on NASA Missions, Projects, and Applications

Dara Entekhabi [Massachusetts Institute of Technology (MIT)—*SMAP Science Team Leader*] introduced SMAP as a mission designed to increase our understanding of the processes that link the terrestrial water, energy, and carbon cycles. The primary data products of the SMAP mission are maps of surface- and root-zone soil moisture, while soil freeze/thaw state, carbon net ecosystem exchange, calibrated brightness temperature, and vegetation optical depth products are also generated. Entekhabi identified several current and future application areas where SMAP can support USFS management needs, including forest and rangeland monitoring, hazards assessments, forest fuel load, dryness and ignition hazard, tree mortality, and carbon stocks. He also demonstrated applications of SMAP soil moisture for drought monitoring and early warning. In addition, **Andreas Colliander** [NASA/Jet Propulsion Laboratory (JPL)—*SMAP Project Team Member*] presented information on SMAP soil moisture across different vegetation types and discussed an upcoming SMAP field campaign focused on trees and forested areas. **Matt Reeves** [USFS] presented material on how SMAP soil moisture could be used to support a rangeland monitoring system.

[2] Latency is defined as the approximate time it takes from data acquisition by a satellite until those data reach an end-user in a usable format.

Amy Neuenschwander [University of Texas at Austin—*ICESat-2 Land and Vegetation Data Product Lead*] provided an overview of the ICESat-2 mission and data products relevant to land managers, and reviewed the Along-track Land/Vegetation Data Product (ATL08). In addition to its focus on the poles, ICESat-2 will also collect range measurements of terrain, vegetation, and water, globally. These include estimates of vegetation height—differentiated between flooded and nonflooded vegetation (e.g., mangroves)—ocean surface height, inland water height, and near-shore bathymetry. She explained that this information has a range of potential land management applications, including biomass mapping, habitat and biodiversity monitoring, fuel load estimating, and snowpack monitoring, among others. **Birgit Peterson** [USGS] demonstrated the use of ICESat-2 data for operational wildland fuels assessment and mapping, while **Randolph Wynne** [Virginia Tech] described the application of satellite imagery and lidar data to monitoring and assessment of forest growth, removals (e.g., clearcut logging), and management intensity (e.g., thinning for fire prevention).

Ralph Dubayah [University of Maryland, College Park (UMD)—*GEDI Principal Investigator*] described GEDI as a science investigation mission that seeks to quantify forest biomass, disturbance and recovery, carbon sequestration potential, and vertical forest structure and its relationship to biodiversity. Dubayah and **John Armston** [UMD] explained how GEDI could provide valuable data for a variety of USFS applications, including county-scale biomass estimates from Forest

Table 1. List of presenters from USFS and topics covered.

Presenter [*Title*]*	**Topic**
Raha Hakimdavar [*Hydrologist*]	Soil Moisture and Hydrology
Michele Slaton [*Ecologist*]	Vegetation Structure and Function
Grant Domke [*Research Forester*]	Emissions and Flux
Danny Lee [*Director of Eastern Forest Environmental Threat Center*]	Information Needs for Early Warning Systems
Kevin Megown [*Resource, Mapping, Inventory, and Monitoring Program Lead*]	Resource Mapping Inventory and Monitoring

*All presenters were from USFS.

Inventory and Analysis (FIA)[3] for both calibration and validation, initialization data for prognostic ecosystem and carbon flux models, conservation and biodiversity studies, and parameterization of fire models. Even though GEDI's relatively short nominal mission length of two years may limit operational applications of its data, USFS attendees were encouraged to be creative in developing applications that demonstrate the usefulness of GEDI data to provide support for follow-on mission proposals. First delivery of GEDI data to NASA Distributed Active Archive Center (DAACs) is scheduled to occur in fall 2019.

Sassan Saatchi [JPL] and **Natasha Stavros** [JPL—*NISAR Deputy Program Applications (DPA) Co-Lead*] demonstrated how NISAR could help the USFS detect changes in biomass, disturbance, and inundation. Saatchi emphasized that NISAR will provide the first dedicated global observations to be used for monitoring changes of forest carbon stocks; forest cover from disturbance (e.g., fire, hurricane, insects, and droughts); recovery after disturbance or timber logging; and forest health and productivity, by providing habitat structure, changes of canopy water content, monitoring soil moisture changes, and drought stress.

George Hurtt [University of Maryland (UMD)—*CMS Science Team Leader*] provided an overview of NASA's Carbon Monitoring System (CMS). **Edil Sepulveda Carlo** [SSAI/GSFC—*CMS Deputy Program Applications Lead*] described CMS data products and applications. Both presentations highlighted examples of CMS data products related to carbon stocks, emissions, and flux that could be useful for USFS. **Andrew Lister** [USFS Northern Research Station] and **Hans-Erik Andersen** [USFS Pacific Northwest Research Station—*CMS Co-Investigator*] described how the USFS FIA units employ high-resolution aerial imagery for field campaign preplanning—thereby saving time and money—as well as intersurvey, image-based change estimation. As an example, he showed high-resolution aerial imagery from the National Agricultural Imagery Program.[4]

Breakout Sessions Focus on Data Gaps, Technology Challenges, and Opportunities

The workshop featured three breakout sessions on soil moisture and hydrology, emissions and flux, and vegetation structure and function. During each of these breakouts, participants discussed key opportunities and challenges around NASA technology utilization by land management agencies. Based on the soil moisture and hydrology panel discussion, the sparse forest soil moisture network limits the ability of USFS managers to monitor and detect changes to guide management decisions. Meanwhile, the vegetation structure and function panel discussion highlighted information needs on post-disturbance recovery, species specific density and canopy cover, and understory and shrub characterization and phenology. The emissions and flux panel discussion emphasized that despite the number of carbon monitoring maps available worldwide, not all maps are compatible with a country's institutional needs and readiness. All three panels agreed that there are gaps in science and applications of satellite data products, along with challenges in translation of agency language and needs, preventing managers from holistically using satellite data in their decision-support systems.

Based on these sessions, key opportunity areas for USFS and NASA collaboration may include developing a strategic framework for collaboration and coordination; supporting working groups and engaging in NASA mission Early-Adopter programs; developing needs requirements and study feasibility; and collaborating to integrate tools and data.

Tools and Hands-On Data Tutorials

The workshop also included presentations and hands-on data tutorials aimed at increasing awareness of existing USFS relevant tools and build capacities to integrate NASA data products to support natural resource management needs. The sessions showcased tools[5] to visualize, access, and download NASA data, including presentations from the USFS and several of NASAs Distributed Active Archive Centers.[6] Presenters included **Sean Healey** [USFS—*CMS Principal Investigator* and *GEDI Science Definition Team Member*], **Jeremy Kirkendall** [NASA HQ—*Senior GIS Administrator in Applied Science Program*], **Paul Moth** [National Snow and Ice Data Center (NSIDC)], **Yaxing Wei** [ORNL], **Amy FitzGerrell** [NSIDC], and **Heidi Kristenson** [Alaska Satellite Facility (ASF)].

In addition, the workshop facilitated two scenario-based, hands-on data tutorials. **Paul Moth**, **Yaxing Wei**, **Heidi Kristenson**, and **Marc Shapiro** [all from Creare, LLC] conducted a tutorial on soil moisture

[3] The USFS Forest Inventory and Analysis program is a continuous forest census that provides the information needed to assess America's forests through annual surveys. Learn more at *https://www.fia.fs.fed.us/library/fact-sheets/index.php*.

[4] The National Agriculture Imagery Program (NAIP) acquires aerial imagery during the agricultural growing seasons in the continental U.S. A primary goal of the NAIP program is to make digital orthorectified photography available to governmental agencies and the public within a year of acquisition. Learn more at *https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/index.*

[5] The tools demonstrated are described in the workshop agenda referenced earlier.

[6] To learn more about NASA's DAACs and related data distribution topics, see "Earth Science Data Operations: Acquiring, Distributing, and Delivering NASA Data for the Benefit of Society" in the March–April 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 2**, pp. 4-18—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/March%20April%202017%20color%20508.pdf#page=4*]. **Note**: A Table listing the DAACs is found on pp. 8-9 of this article.

trends called "What is the trend in soil moisture and how does this compare to regional trends?" **Birgit Peterson** [USGS], **Jim Ellenwood** [USFS], and **Nolan Cate** [USFS] led a tutorial on vegetation structure assessments, called "How to leverage sampling observations for regional vegetation structure assessments (approaches and limitations)."

The vegetation structure assessments tutorial allowed participants to learn how to access and analyze an ICESat-2 vegetation data granule, which had been released exclusively for the workshop. It also highlighted prelaunch research findings from **Lana Narine** [Texas A&M University] and from two ICESat-2 Early Adopters,[7] **Nancy Glenn** [Boise State University] and **Randolph Wynne** [Virginia Polytechnic Institute and State University]. In addition, **Birgit Peterson** and **Sabrina Delgado Arias** [GSFC/SSAI—*ICESat-2 Program Applications Coordinator*] provided an overview of NASA's Early Adopter Program.

Conclusion and Follow-On Activities

The workshop was the first collaborative effort to bring together multiple representatives from NASA missions and projects, NASA DAACs, USFS, and other relevant entities. This user-driven workshop promoted and strengthened partnerships across agencies to increase use of EO data in support of land and natural resource management goals.

The workshop concluded with a plenary session to share and discuss initial findings from the workshop, prioritize identified gaps and plans to close the gaps, and solidify and plan for follow-on activities—including coauthoring the workshop proceedings. Further, USFS and NASA are working on ways to foster continued engagement, more efficiently share data, and identify further commonalities. This also includes developing formal agreements for future collaboration.

Attendees deemed the workshop successful and voiced their commitment to maintaining the momentum built during the meeting. Post-workshop meetings of the workshop planning committee are ongoing and aimed at continuing the collaboration and coordination of follow-on activities to enhance the use of NASA data products to support sustainable natural resource management.

Acknowledgements

The authors would like to sincerely thank **Raha Hakimdavar** [USFS], **Peggy O'Neill** [GSFC], **Nancy Glenn** [Boise State University], and **Andrew Hudak** [USFS] for their contributions to this summary. ■

[7] ICESat-2 Early Adopters are groups and individuals who have a direct or clearly defined need for ICESat-2 data, who have an existing application, who have an interest in utilizing a proposed ICESat-2 product, and who are capable of applying their own resources (funding, personnel, facilities, etc.) to demonstrate the utility of ICESat-2 data for their particular system or model. To learn more, see "Early Adopters Prepare the Way to Use ICESat-2 Data" in the July–August 2015 issue of *The Earth Observer* [**Volume 27**, **Issue 4**, pp. 31-35—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/July%20August%202015_col_508.pdf#page=31*].

Summary of the First NASA Harvest Conference

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Introduction

The NASA Harvest Conference took place on June 25, 2019 at NASA Headquarters in Washington, DC. In the first meetings of its kind, approximately 200 agriculture and food security professionals met together to discuss innovative ways of using satellite and other Earth observation (EO) data. As its name suggests, the conference host was the NASA Harvest Consortium, a multidisciplinary program commissioned by NASA's Applied Sciences Program, led by the University of Maryland, and composed of over 40 international partners. For more information on the organization, visit *https://nasaharvest.org*.

This summary begins with brief background information on NASA Harvest and the NASA Harvest Consortium, and on the motivation for this conference, followed by a review of the highlights of the conference.[1] The full presentations are available on Google drive at *http://bit.ly/HarvestConf*. Readers can view the NASA Harvest Conference Wakelet (*https://wke.lt/w/s/HNjDJn*) for a consolidated archive of tweets and videos from the Conference (Twitter Handle: *@NASAHarvest*; all video content: *http://tiny.cc/HarvestTube*).[2] To read more about NASA Harvest partners' projects, visit *http://NASAHarvest.org/projects*.

Background on NASA Harvest and NASA Harvest Consortium

NASA Harvest is led by and coordinated at the University of Maryland Center for Global Agricultural Monitoring Research (UMD CGAMR). Harvest is made up of over 40 partner organizations from around the world that use EO to advance agriculture and food security.

The **Figure** below illustrates the organization of the NASA Harvest Consortium. The Harvest Hub, located at the CGAMR, directs and coordinates the Harvest Consortium and interacts with NASA Headquarters (HQ) for programmatic, technical, and scientific reachback across multiple NASA centers. The Harvest leadership team includes **Inbal Becker–Reshef**, **Chris Justice**, and **Alyssa Whitcraft** [all from UMD], all of whom had leadership roles in the conference (and whose positions are formally listed in the **Table** on page 39).

[1]There is a more-condensed summary posted online at *https://nasaharvest.org/news/nasa-harvest-conference-brings-together-voices-across-spectrum-food-systems-and-satellites*. Some of the material in that report provided the basis for this article of *The Earth Observer*.

[2] To stay up to date on the latest news from NASA Harvest, subscribe to the newsletter at *https://myemail.constantcontact.com/NASA-Harvest-Conference-Recap.html?soid=1130191479667&aid=B9vM9WJvJAk*.

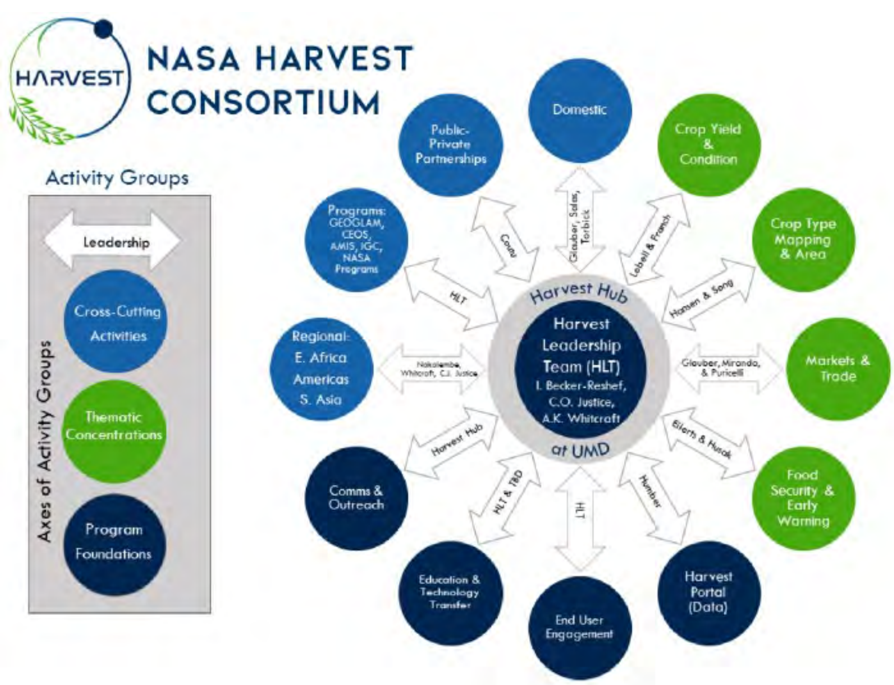


Figure. This is the NASA Harvest Consortium's programmatic organization chart, which identifies its cross-cutting activities, thematic concentrations, and program foundations, each of which has co-leadership from key actors in the program from around the world. At the center is the Hub, situated to facilitate cross-program collaboration, synthesis, and synergy. **Image credit**: NASA Harvest

The Harvest Hub anchors a broad network of cross-disciplinary partners drawn from universities, government agencies and government research organizations, NGOs, international multi-lateral organizations, and the private sector, representing end users, information and service providers, and applications researchers. The distributed organizational structure is designed to facilitate the overarching goal of advancing the awareness, use, and adoption of satellite-based EO in order to empower decisions that support food security, stable markets, economic progress, and sustainability.

Motivation for Meeting

At its core, the conference aimed to bring together actors from across the food security and agricultural markets domains, regardless of their current usage of EO data and analytics. Central to this is the understanding that sustainably feeding the planet will require successful partnerships between public research and operations agencies and private sector actors, as well as capitalizing on as-yet uncaptured opportunities. There are clear avenues for cross-sectoral collaboration to

Table. Summary of Harvest Conference sessions.*

Session Title	Moderator [Harvest Role]	Panelists and Affiliations	Keynote Speakers and Affiliations
Earth Observations, Agricultural Markets, and Food Price Volatility	Inbal Becker-Reshef [Harvest Director]	Abdolreza Abbassian [AMIS]**, Seth Meyer [USDA], Arnaud Petit [International Grains Council], and Ian Jarvis [GEOGLAM]	Joe Glauber [IFPRI], Matt Hansen [UMD], and Esteban Copati [BAGE]
Public-Private Partnerships in EO for Agriculture	Alyssa Whitcraft [Harvest Associate Director & Program Manager]	Sara Menker [Gro Intelligence], Molly Brown [6th Grain], Gerald Masila [Eastern African Grain Council], Rhiannan Price [Maxar], Pierre Sibiry Traore [Manobi and ICRISAT], and Molly Jahn [University of Wisconsin]	Sylvain Coutu [Swiss Re], Bill Salas [Applied Geosolutions], and Kaiyu Guan [University of Illinois]
Food Security and Early Warning	Catherine Nakalembe [Harvest Eastern Africa Lead]	Rogerio Bonifacio [World Food Programme], Mario Zappacosta [UM Food & Agriculture Org], Kenneth Mwangi [ICPAC], and Gary Eilerts [USAID]	Catherine Nakalembe on behalf of Martin Owor [Office of Prime Minister Uganda], David Lobell [Stanford University], Tim McCully [Lutheran World Relief], and Jim Verdin [USAID]
Priorities for Integrating EO into Agricultural Policy and Global Food Security: Connecting Actors Along the Data-to-Decisions Cycle	Chris Justice [Harvest Chief Scientist]	Warren Preston [USDA], Stan Wood [Gates Foundation], Kiersten Johnson [USAID], Jean-Luc Bald [European Commission], Benjamin Koetz [European Space Agency], Joe Mascaro [Planet], and Lawrence Friedl [NASA]	No Keynotes in this session

* Abbreviations and acronyms not expanded or defined here are expanded in the text of the article. ICPAC is a compound acronym that stands for IGAD Climate Prediction and Application Centre; IGAD stands for Intergovernmental Authority on Development.
** Participated *via* WebEx.

NASA Administrator Jim Bridenstine addresses attendees at the first NASA Harvest Conference. **Photo credit**: NASA Harvest

meaningfully impact agricultural resilience and environmental sustainability. Harvest will facilitate public-private partnerships globally and domestically, and is exploring collaborations with major consumer goods organizations, supply chain companies, and agricultural services companies to swiftly move EO data analytics into industry, where many key agricultural land use and management decisions are made.

Workshop Highlights

The meeting began with some opening remarks summarized below; the remainder of the day was divided into four sessions, as listed in the **Table** on page 39. Each session included a panel discussion that featured distinguished panelists from national organization representatives, humanitarian organizations, research institutions, nongovernmental organizations (NGOs), and industry. Each brought a unique perspective on the value, challenges, and opportunities for EO tools and data to monitor and predict crop health, inform agricultural markets, and prevent food price volatility. Three of the four sessions also featured keynote presentations with topics that complemented the subject matter discussed in the panel discussions.

Presentations and panel sessions were designed to feature the full research-to-operations transition continuum around developing—and then using—satellite data for agricultural monitoring and decision-making. Both remote sensing scientists and end-users provided their unique perspectives as they highlighted early program achievements. They also addressed challenges and opportunities that lie ahead for Harvest as it seeks to advance both the science of agricultural remote sensing and its operational transition for decision support. In the words of **Inbal Becker-Reshef** [NASA Harvest—*Program Director*], "It's a really exciting time for satellite-based agricultural monitoring—a completely new era in terms of our capabilities, revolutionizing what we can do." With the organization of this conference, NASA Harvest and its partners seized the opportunity to increase awareness, form new connections, and strengthen existing relationships around these themes across multiple sectors and geographic regions.

Opening Remarks

"This is one of the most important things NASA does—measuring and improving food security."

—NASA Administrator Jim Bridenstine

The meeting began with remarks from **NASA Administrator Jim Bridenstine** [shown in photo above]. He said that, "Because of the activities of the people in this room, lives are going to be improved, lives will be transformed, disasters that would have otherwise happened will not happen." Following the Administrator's opening remarks, **Lawrence Friedl** [HQ—*Director of* the *Applied Sciences Program*] emphasized that the Harvest Consortium's flexibility to collaborate on short- and long-term projects across many different sectors will "…help [NASA] learn effective ways to advance the usage of Earth observations."

Session 1: Earth Observations, Agricultural Markets, and Food Price Volatility

Joe Glauber [International Food Policy Research Institute (IFPRI)—*Senior Research Fellow*] explained how Earth observation technologies will improve timeliness and accuracy of crop production forecasts, which can bring transparency to markets that are subject to price volatility. Glauber is a former U.S. Department of Agriculture (USDA) Chief Economist and co-lead of Harvest's Markets and Trade Activity Group. Market volatility in 2011 led to the G20[3] establishing the Agricultural Market and Information System (AMIS) and the Group on Earth Observations Global

[3] The G20 is a forum that is used to discuss policies surrounding international financial stability. The forum was originally formed in 1999. The G20 is made up of a group of nations with the most advanced and emerging economies in the world.

Agricultural Monitoring (GEOGLAM) Initiative.[4] **Esteban Copati** [Buenos Aires Grain Exchange (BAGE)—*Head of Agricultural Estimations*] further supported this view, adding that the partnership with Harvest increased the accuracy of their estimations and facilitated intra- and international relationships with organizations that further support their ability to make accurate predictions.

Matt Hansen [University of Maryland, College Park (UMD)—*Director, Global Land Analysis and Discovery Group* and *Co-lead of Harvest's Crop Type Mapping and Area Estimation Activity Group*] discussed operational monitoring of key commodity crops via a probability-based method. The technique utilizes automated mapping algorithms combined with field data to derive unbiased, within-season crop-area estimates at low-cost. Hansen tested this method for in-season soybean, maize, cotton, and wheat; maps have been prototyped for multiple countries through collaborative partnerships, e.g., those with Brazil's Companhia Nacional de Abastecimento (Conab) and its space agency, Instituto Nacional de Pesquisas Espaciais (INPE), as well as Argentina's Ministry of Agroindustry and Instituto Nacional de Tecnología Agropecuaria (INTA). **Warren Preston** [USDA—*Deputy Chief Economist*] added that Russia and China are two countries that provide very little information or crop data and that these are places where EO data could provide some clarity and transparency. In fact, recently the G20 AMIS requested that G20 GEOGLAM utilize satellite data to derive area estimates for maize for China, a request which will be fulfilled by Hansen and the Harvest Consortium as a contribution to GEOGLAM.

Session 2: Public-Private Partnerships in EO for Agriculture

Sylvain Coutu [Swiss Re Group—*Head of Innovation*] leads Harvest's Public-Private Partnerships (PPP) Activity Group. He opened the session by outlining Harvest's objectives with respect to PPP: broadly, accelerating the adoption of EO data and analytics by actors across agricultural value chains by developing, documenting, and scaling successful models for partnerships. Coutu emphasized that success lies in identifying win-win opportunities and structuring sustainable cost-sharing models. **Bill Salas** [Applied GeoSolutions (AGS)—*Founder*] is the colead of Harvest's Domestic Activity Group and is supporting the Harvest PPP activity development in the U.S. His company develops platforms and tools that bring EO data and analytics to users across *agricultural value chains*[5] in both public and private sectors. He explained how public-private partnerships can create additional market opportunities for farmers, particularly with respect to implementing conservation management and regenerative agriculture techniques. Salas and others on the panel emphasized that these partnerships can go far in addressing many different stakeholder needs if the relationships are based on trust and transparency, a shared vision, and clear roles and responsibilities for the various actors with often differing agendas. He provided examples of successful public-private partnerships, including one with the common goal of improving soil health and measuring the benefits of soil conservation practices in the U.S. Corn Belt. That partnership includes AGS, the Conservation Technology Information Center (CTIC),[6] the Foundation for Food and Agriculture Research (FFAR),[7] The Nature Conservancy,[8] USDA, and others.

Photograph of some of the panelists and keynote speakers from the Harvest Conference. *Left to right*: Molly Brown, Bill Salas, Rhiannan Price, Sylvain Coutu, Kaiyu Guan, Alyssa Whitcraft, Sara Menker, Molly Jahn, Pierre C. Sibiry Traoré, and Gerald Masila. Affiliations are listed in the Table on page 39. **Photo credit**: NASA Harvest

[4] Harvest is NASA's primary contribution to GEOGLAM. For more on this activity, check GEOGLAM's website, *www.geoglam.org*, and GEOGLAM Crop Monitor website, *www.cropmonitor.org*. AMIS is a group of chief economists from ministries of agriculture around the world that focuses on bringing transparency to supply, demand, trade flows, and prices of key agricultural commodities. GEOGLAM works to provide international consensus on global crop supply outlooks from EO data to support AMIS, while working with the individual national ministries to improve their use of EO for within-season crop monitoring.

[5] An agricultural value chain refers to all of the actors, processes, goods, and services necessary for an agricultural product to move from seed to final customer or consumer. This includes farmers, processors, packagers, distributors, and retail outlets, among many others.

[6] The Conservation Technology Information Center (CTIC) is a national public-private partnership that envisions the widespread use of economically and environmentally beneficial agricultural systems. The organization is supported by the U.S. Environmental Protection Agency, USDA Natural Resources Conservation Service, and other public entities. For more information, visit *https://www.ctic.org*.

[7] The Foundation for Food and Agriculture Research (FFAR) builds unique public-private partnerships to support innovative science addressing today's food and agriculture challenges. For more information, visit *https://foundationfar.org*.

[8] The Nature Conservancy is a global environmental nonprofit working to create a world where people and nature can thrive. For more information, visit *https://www.nature.org/en-us*.

Session 3: Food Security and Early Warning

In addition to moderating this session, **Catherine Nakalembe** [NASA Harvest—*Eastern Africa Lead*] gave a presentation on behalf of **Martin Owor** [Office of the Prime Ministry, Uganda—*Commissioner, Department of Relief, Disaster Preparedness, and Management*], describing Uganda's partnership with Harvest—see *NASA Data Saves Lives and Promotes National Resilience in Uganda* below. Several subsequent speakers and panelists then highlighted three recurrent themes, as described below:

1. *Lack of access to consistent, high quality ground-truth data remains an issue for EO adoption*: One of the largest barriers to broader adoption of EO for agricultural assessments is the lack of high-quality ground-truth data to calibrate, validate, and substantiate what the satellite data show. The trust built through an accuracy assessment afforded by ground-truthing is essential to delivering on the investments NASA and others have made in EO, beginning five decades ago. To make concrete progress, Harvest aims to coordinate the development of community standards around the collection of ground-truth data for use by multiple communities.

2. *Need to reduce overlapping efforts and increase coordination in humanitarian efforts:* **Gary Eilerts** [U.S. Agency for International Development (USAID) Famine Early Warning Systems Network (FEWS NET)—*Co-lead of Harvest Activity Group on Food Security & Early Warning*] pointed out that trust between researchers and end-users needs to develop in order to increase impact of collaboration. He views Harvest as a platform that allows for proliferation of collaborative efforts, decreasing the silo effect of having many different people work towards the same goals individually, rather than together.

3. *Value of public-private partnerships in food security-early warning*: **David Lobell** [Stanford University, *Co-lead of the Harvest Activity Group on Crop Yield and Condition*] argued that there is untapped potential in combining academic research and other capabilities with public-sector research and the resources of the private sector, echoing the theme of the earlier PPP panel.

Session 4: Priorities for Integrating EO into Agricultural Policy and Global Food Security: Connecting Actors along the Data-to-Decisions Cycle

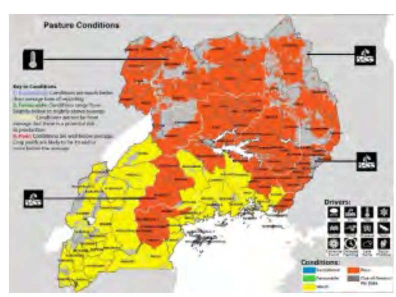
The final session pulled together several prominent voices in the EO, agriculture, and food security fields to illuminate the themes of the day. The panel highlighted that critical uncertainties around the state of agriculture—in both large export countries as well as developing countries most at risk of food insecurity—threaten markets and human livelihoods at multiple scales. It further emphasized the need to improve coordination across actors working in the same regions and topics, to tackle these uncertainties, as well as to both optimize resource usage and minimize "burden" on end-users. Harvest's unique Consortium approach with a centralized Hub enables this sort of coordination.

NASA Data Saves Lives and Promotes National Resilience in Uganda

Crop failure can have devastating impacts on farmers' livelihoods and on food security. Early warning—which is uniquely provided through application of NASA Earth observations—gives governments time to act proactively and mitigate loss and damage.

Photo credit: Catherine Nakalembe

Crop conditions in Uganda are monitored throughout the growing season (May through September) using the UMD-developed Global Agricultural Monitoring (GLAM) East Africa System, which shows crop and vegetation condition over time using NASA MODIS and VIIRS[*] data. Both of these projects are now supported under NASA Harvest.



GEOGLAM Crop Monitor for Uganda (July-August 2017) shows watch and poor conditions across all in-season croplands. NASA data are a core input, and the GEOGLAM Crop Monitor was developed and coordinated by UMD with support from USAID and NASA Applied Sciences. **Image credit:** GEOGLAM Crop Monitor

In Uganda, the Office of the Prime Minister Department of Relief, Disaster Preparedness, and Management (OPMDPM) utilizes GLAM and its NASA data as the primary trigger for the country's Disaster Risk Financing (DRF) fund. For example, in May 2017, satellite data showed drought conditions that would lead to widespread crop failure in Uganda. By August 2017, the GEOGLAM Crop Monitor for Early Warning (CM4EW)[**]—an international report using satellite data to monitor crop conditions—confirmed outlooks for final production

continued on next page

were poor—see example CM4EW output for Uganda [*right*]. Based on these forecasts, the OPMDPM triggered the DRF.

The OPMDPM paid out DRF funds directly to farmers to abandon their crops, buy new seeds to sow, and in the interim undertake public works to improve local infrastructure. This averted a crisis, reduced the need for foreign aid, and improved allocation of their own resources, all while supporting their national autonomy.

Photo credit: Catherine Nakalembe

In 2017, the OPM paid out 4.11 million USD to 31,386 Ugandan households (roughly 150,000 individuals). The Ugandan government saved 2.6 million USD. In **Martin Owor's** words [OPMDPM—*Commissioner*], "In the past we always reacted to crop failure, spending billions of shillings to provide food aid in the region. 2017 was the first time we acted proactively because we had clear evidence from satellite data very early in the season."

[*] MODIS stands for Moderate Resolution Imaging Spectroradiometer, which flies on NASA's Terra and Aqua platforms; VIIRS stands for Visible–Infrared Imaging Radiometer Suite, which flies on the Suomi National Polar-orbiting Partnership (NPP) and NOAA-20 satellites. (NOAA stands for National Oceanic and Atmospheric Administration.)

[**] To learn more about CM4EW and another food security and early warning activity in Southern Africa in which NASA Harvest is a partner, see "Increasing Information Access for Food Security Monitoring: Overview of the GEOGLAM Crop Monitor for Early Warning (CM4EW)" in the May–June 2019 issue of *The Earth Observer* [**Volume 31**, **Issue 3**, pp. 4-14—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/May_Jun_2019_color.pdf#page=4*].

Conclusion

At the close of the Conference, **Alyssa Whitcraft** [NASA Harvest—*Associate Director and Program Manager*] summed up the underlying nature of the Harvest Consortium and the spirit of the conference: "Everyone has a role to play in promoting sustainable agriculture, feeding the planet, and promoting food security." By facilitating collaboration and leveraging its unique programmatic flexibility, agility, and innovative structure, NASA Harvest, along with its expansive group of partners, is taking proactive steps toward reaching these goals.

The gathering demonstrated that there is significant interest in capitalizing upon the overlapping objectives of actors in the food security and agriculture space; taking direct steps to implement the vision of the event is next. Harvest, as a consortium of funded and unfunded collaborator partners who represent the state of the science of agricultural assessment using EO and the state of practice of food security action is particularly well-positioned to support the implementation of this collective vision as well as to support the community in identifying opportunities for cross-sector and cross-program activities.

Making the case for the value of NASA investments in agriculture has never been more important. The extraordinary, real-world impacts of using satellite data are becoming ever more evident as we include end-users in discussions and project designs from their inception. EO tools will play a critical role in the "digital agriculture" transformation currently underway, which could lead to trillions of dollars of economic growth while promoting sustainable resource use and food security. ■

Summary of the 2019 Earth Science Technology Forum

Elizabeth Goldbaum, NASA Earth Science Technology Office, elizabeth.f.goldbaum@nasa.gov

Introduction

For three days in mid-June, over 200 scientists and engineers gathered at NASA's Ames Research Center (ARC) to delve into the details of current and planned cutting edge technologies to help us better understand Earth.

The Earth Science Technology Forum (ESTF) ran from June 11-13, 2019. The Earth Science Technology Office (ESTO; *https://esto.nasa.gov*) hosts the event each year,[1] with the intent of sharing information and fostering collaboration among academic, government, and commercial researchers to advance Earth science technologies. ESTO is part of NASA's Earth Science Division (ESD) and is responsible for managing the Agency's Earth science technology program and funding the development of nascent Earth science technologies, from tiny instruments aboard shoebox-sized satellites to machine-learning algorithms that digest and analyze large Earth science datasets.[2]

Over three days, attendees could participate in nine technical sessions to learn about technologies that help answer questions under these Earth science umbrellas:

- Surface Topography, Geology, Biology, and Vegetation;
- Snow, Ice, and Snow Water Equivalent;
- Distributed Missions and Constellations;[3]
- Sustainable Land Imaging;
- Soil Moisture, Mass Change, and Surface Deformation;
- Atmospheric Winds and Ocean Surface;
- Clouds, Convection, and Precipitation;
- Radiation Balance; and
- Aerosols, Ozone, and Trace Gasses.

Interspersed between the technical sessions were six plenary sessions, featuring leaders from NASA, Planet Labs, Lockheed Martin, and Google. Attendees also had an opportunity to mingle during a poster session on the second day. **Philip Larkin** [ESTO—*Advanced Planning Program Lead*] chaired the meeting.

This article presents the highlights from the forum. Readers are directed to *https://esto.nasa.gov/forum/estf2019/sessions.html#S1* for the full agenda, abstracts, and links to individual presentations.

Plenary Highlights

Throughout the conference, six plenary speakers shared remarks about their organizations and goals. One of the more popular presentations, according to a post-forum survey—and relevant to readers of *The Earth Observer*—is described in the narrative here; the other five are briefly summarized in **Table 1**.

[1] ESTO hosted its first ESTF in 2003. The conference location alternates between the east and west coasts each year, and welcomes researchers from across the world.

[2] To learn more about ESTO, see "ESTO: Benefitting Earth Science through Technology" in the May–June 2013 issue of *The Earth Observer* [**Volume 25, Issue 3,** pp. 22-29—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/May_June_2013_508_color.pdf#page=22*].

[3] Unlike the other sessions, which each focused on a particular area of Earth Science research, this session focused more on mission operations and engineering.

Table 1. Plenary presentations during the 2019 Earth Science Technology Forum.

Speaker [Affiliation]	Topic
David Korsmeyer [NASA's Ames Research Center (ARC)—*Associate Center Director for Research*]	Described research facilities at ARC, including the extensive wind tunnels sprawled across campus, and research areas, e.g., aerosol and radiation studies.
Ignacio Zuleta and **James Mason** [both at Planet]	Discussed remote sensing with disaggregated CubeSat constellations. Planet was founded in 2010 out of ARC and strives to image the whole world every day.
Matthew Fladeland [ARC—*Manager of NASA's Airborne Sciences Program (ASP)*]	Summarized airborne missions from across the world and explained how the ASP enables interesting Earth science research and can be a training ground for the next generation of engineers and scientists.

continued on next page

Table 1. Plenary presentations during the 2019 Earth Science Technology Forum. (Continued)

Speaker [Affiliation]	Topic
Nelson Pedreiro [Lockheed Martin—*Vice President of Advanced Technology Center (ATC)*]	Gave an overview of the ATC, which, from the 1960 launch of TIROS-1, the nation's first weather satellite, has delivered over 100 satellites to monitor weather and the environment.
Peter Norvig [Google LLC—*Director of Research*]	The former leader of ARC's Computational Sciences Division focused on the importance of *machine learning*,* which helps scientists solve big questions much faster than they could on their own; he encouraged scientists to put on their "programming hats" as they look to the future.

*Machine learning is a method of data analysis where "the system" learns from the data, e.g., to identify patterns, and can make decisions without human intervention.

Jack Kaye [NASA HQ—*Associate Director of Research for the ESD*] gave a plenary presentation in which he discussed the interplay between technology and research for Earth science. While he jokingly referred to himself as a "technoturtle," his remarks made it clear that he was an avid supporter of technology nonetheless. Kaye emphasized that we can better observe, model, and analyze Earth when ESTO and other programs within NASA, as well as non-government entities, advance technologies that allow us to explore new areas of inquiry. "I value the work that you do to bring NASA into the future," Kaye said to the ESTF attendees.

Presentations on Information Technology

Over the course of the three-day meeting, various speakers shared projects centered on deciphering and disseminating *big* Earth science datasets. A selection of those presentations are summarized below.

Margaret Wooten [NASA's GSFC] and her team—led by **Christopher Neigh** [GSFC]—are working on a project to provide high-resolution products for NASA's Earth science investigators. Their work aims to provide tools as an Application Program Interface (API) to make commercial Earth observation data available and accessible to NASA-funded researchers. Commercial high-resolution satellite data provide global coverage that can support existing NASA Earth observing missions. Through agreements with the National Geospatial-Intelligence Agency, GSFC is acquiring petabytes of sub-meter to four-meter (~13-ft) resolution imagery from around the globe using the WorldView-1, -2, -3, -4; Quickbird-2; GeoEye-1; and IKONOS-2 satellites. Prior to 2008 these datasets were spatially disparate and primarily used to evaluate and validate coarser resolution data products. With this new technology, these currently underused data will be available for the enhancement of NASA Earth observation science.

Ved Chirayath [ARC] described a project called Neural Multi-Modal Observation and Training Network (NeMo-Net). He and his team are developing a machine-learning algorithm for mapping coral reefs with remote sensing at different scales. "Life depends on these systems," Chirayath said. NeMo-Net is a framework set up like an interactive video game, where players, or citizen scientists, dive off a boat to study the coral in the ocean below to help understand how many and what kind of corals live in the ocean.[4] Chirayath stated that a global map of coral reef distribution should be available by December 2019.

Charlie Zender [University of California, Irvine] introduced a software called Justified Arctic Weather Station (JAWS), which reformats Arctic weather station data to an easy-to-use format so that scientists can better understand weather locally and assess climate change impacts globally. Earth scientists rely on Arctic weather data to better model and predict climate change. The problem is not so much lack of data. There are multiple weather stations throughout the Arctic—including 40 in climatically sensitive Greenland. However, each station collects weather data in its own format, which makes it difficult to share information between stations and look at weather and climate across the region. JAWS aims to change that by putting all the data from all the stations in the same format. The software's name pays homage to the "justify" tool in *Microsoft Word*, which formats mismatched paragraphs into perfect rectangles.

Bart Forman [University of Maryland, College Park] shared a computer-based tool that uses machine learning to help determine the most effective combination of satellite-based sensors to produce the most comprehensive data. In the western U.S., snow is the main source of drinking water, and water from snow is a major contributor to hydroelectric power generation and agriculture.

Andy Wood [National Center for Atmospheric Research's (NCAR) Research Applications Laboratory] is working with his team to localize global climate projections. Climate change can increase water demand while limiting its availability. This effort aims to help water managers at the local, state, and federal level more easily understand how climate change compromises

[4] An online article in *EOS: Earth & Space Science News* describes the game in more detail—see *https://eos.org/articles/coral-reef-video-game-will-help-create-global-database*.

water security in their communities. The project's tools will help water managers create strategies to modernize and maintain their infrastructure.

Branko Kosovic [NCAR] discussed how *fuel moisture* (i.e., the amount of moisture in the available "fuel" or vegetation), terrain, and weather are key factors in determining the likelihood of wildfires. To help firefighters and decision makers better understand fire risks, Kosovic and his team put together a project that combines MODIS[5] satellite data with water data from ground stations to estimate fuel moisture content.

[5] MODIS stands for Moderate Resolution Imaging Spectroradiometer, which flies on NASA's Terra and Aqua platforms.

Understanding how dry vegetation is in a region can help firefighters determine fire risk.

Presentations on Instruments

Throughout the forum, many of the speakers described efforts to design instruments able to observe Earth in new, cutting-edge, and cost-effective ways. **Table 2** lists a few of these presentations. The entries chosen are intended to give a representative sampling of the variety of airborne and space flight hardware being developed—and the science being studied—through ESTO-funded projects that were showcased at this meeting.

Table 2. Summaries of selected presentations on new sensors, imagers, and other instruments.

Speaker [Affiliation]*	**Topic**
David Osterman [Ball Aerospace]	Compact Infrared Radiometer in Space (CIRiS) is a CubeSat instrument to demonstrate on-orbit longwave infrared radiometric imaging and calibration for Earth science observations.
Lauren Wye [SRI International]	SRI CubeSat Imaging Radar for Earth Science (SRI-CIRES) will fly a moderate-resolution (5-25 m) high-fidelity interferometric synthetic aperture radar (InSAR). InSAR measures ground deformation from space so researchers can improve short-term natural hazard forecasting.
Shivani Joshi [NASA/Jet Propulsion Laboratory (JPL)]	Radar in a CubeSat (RainCube) is the first K_a-band precipitation radar mission on a CubeSat. RainCube's successful mission paves the way for precipitation measurements over smaller time scales to better understand how weather systems evolve. (**Eva Peral** [JPL] is principal investigator of this project.)
Joel Johnson [The Ohio State University]	Ultra-Wideband Software Defined Microwave Radiometer (UWBRAD) is a remote sensing instrument that assesses ice sheets' temperatures and their thicknesses.
Caitlyn Cooke [Northrop Grumman Corporation/JPL]	Integrated Receiver and Switch Technology (IRaST) improves the measurement accuracy of current submillimeter radiometric technology to better observe ice clouds. (**Bill Deal** [Northrop Grumman Corporation] is team leader for this project.)
Dong Wu [GSFC]	Submillimeter-Wave and LWIR Polarimeters for Cirrus Ice Properties (SWIRP) will combine—for the first time—multiple wavelengths to obtain information about the ice crystals making up cirrus clouds. Clouds—and ice clouds in particular—remain a major source of uncertainty in climate models.
Erik Richard [Laboratory for Atmospheric and Space Physics]	Compact Spectral Irradiance Monitor (CSIM) measures solar spectral irradiance from a 6U CubeSat to help scientists understand the Sun's influence over the atmosphere. CSIM's tiny stature and precise measurement capabilities make it an ideal candidate for a future constellation, offering an alternative to current satellite missions.
David Harber [Laboratory for Atmospheric and Space Physics]	Compact Total Irradiance Monitor (CTIM) will measure total solar irradiance. CTIM will demonstrate next-generation technology for monitoring total solar irradiance from a 6U CubeSat. Together, CTIM and CSIM could measure the same quantities as the Total and Spectral Solar Irradiance Sensor (TSIS) mission—at lower cost.

*The speakers listed here were the project leaders/principal investigators unless otherwise specified in the description.

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Philippine Airborne Campaign Targets Weather, Climate Science

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EDITOR'S NOTE: This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

NASA's P-3B science aircraft—see photo [*right*]—soared into the skies over the Philippines on August 25, 2019, to begin a nearly two-month-long investigation on the impact that smoke from fires and pollution have on clouds, a key factor in improving weather and climate forecasts. The Cloud, Aerosol, and Monsoon Processes Philippines Experiment (CAMP^{2}Ex) is the most comprehensive field campaign to date in Maritime Southeast Asia to study the relationship between aerosol particles as they interact with surrounding monsoon meteorology, cloud microphysics, and the Sun's radiation.

NASA's P-3B science aircraft is fitted with remote-sensing instruments to measure a number of variables within and near clouds, including those related to precipitation and cloud droplets as well as aerosol size and composition. **Photo credit**: NASA

Led by NASA, the U.S. Naval Research Laboratory (NRL) and the Manila Observatory in conjunction with the Philippine Atmospheric, Geophysical and Astronomical Services Administration and the Philippine Department of Science and Technology, CAMP^{2}Ex comprises an interdisciplinary, international team of field researchers, modelers, and remote sensing developers.

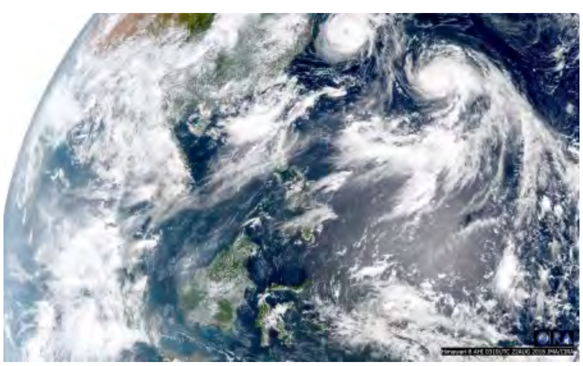

Figure. This image from the Advanced Himawari Imager aboard the JAXA Himawari-8 satellite, from August 21, 2018, shows smoke off the west coast of Borneo and dueling tropical cyclones in the Philippine Sea. **Image credit**: Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University, Japan Aerospace Exploration Agency (JAXA), National Oceanic and Atmospheric Administration (NOAA), and NASA

The study seeks to tackle some of the most difficult weather and climate phenomena to understand, monitor, and forecast. The *Maritime Continent*—comprising Sumatra, Malay Peninsula, Borneo, Sulawesi, the Philippines, and numerous other islands and surrounding seas—has been long sought out as an area of scientific inquiry. Agricultural and deforestation fires from the region along with air pollution from cities provide a ready supply of aerosol particles that influence major weather processes. Besides the torrential monsoons over the Asian archipelago, the region also produces moisture that provides rainfall over the Pacific Ocean and can even influence weather in the continental U.S. (The **Figure** [*left*] shows a satellite image from this region from the Advanced Himawari Imager that flies on the Japanese Himawari-8 satellite; this image gives a feel for the mix of atmospheric phenomena that occur in the CAMP^{2}EX study area.)

"We know aerosol particles can affect clouds and precipitation, but we don't yet have a quantitative understanding of those processes," said **Hal Maring** [NASA Headquarters—*Radiation Sciences Program Manager*]. "Our goal is to improve satellite products and numerical models to help scientists better predict weather and climate."

"Numerous studies have linked the presence of pollution and smoke from agricultural fires and fires from deforestation to changes in cloud and storm properties, but we lack the observations of the actual mechanisms taking place," said **Jeffrey Reid** [NRL]. "CAMP^{2}Ex provides a much-needed crucible for satellite observing systems and model predictions to monitor and understand how atmospheric composition and weather interact."

Aerosol–cloud dynamics have a profound impact on weather and climate, yet there are large uncertainties in how those dynamics affect climate. Aerosol particles include sea salt, dust, air pollutants, and biomass-burning smoke particles; nearly all can act as *cloud condensation nuclei* (also known as *cloud seeds*). Depending on the size and composition of these aerosol particles, water vapor can coalesce around them to form water droplets that may later become rain. But if there is a high concentration of aerosol particles, the clouds may be populated with a larger number of smaller drops, which are less likely to coalesce into rain in smaller clouds.

"Yet recent research shows that these smaller drops may strengthen and increase the longevity of severe storms," Reid said. "It's an intricate science."

According to **Susan van den Heever** [Colorado State University—*P-3B Flight Scientist*], "Complex, nonlinear feedbacks between those processes that form cloud droplets and rainfall and those that drive the upward and downward motions within storms are challenging to accurately represent in numerical models. These feedbacks are important to determine storm severity and the formation of new storms. CAMP^{2}Ex will provide us with unprecedented observations that will allow us to better represent these feedbacks in current research and weather forecasting models."

Smoke and pollution also affect how much incoming sunlight is reflected back into the atmosphere. Particles that are darker in color, such as black carbon from wildfires, absorb sunlight and contribute to global warming. Depending on the type and altitude of the cloud, black carbon may either support or suppress cloud formation; black carbon also affects how much sunlight clouds reflect back into the atmosphere. Quantifying these mechanisms is crucial for improving global climate forecast models.

Maring explained that aerosol-cloud interactions are notoriously difficult to observe in the field, adding that, "some clouds have very short lifetimes while others have very long ones, and they're all located in radically different parts of the skies. Getting a quantitative look at these processes is always a tall order."

To be able to observe cloud and aerosol interactions, along with the associated weather systems, CAMP^{2}Ex leveraged instruments on multiple airborne and ground platforms to record wide-scale meteorology, composition, cloud microphysics, and solar and longwave radiation. NASA's P-3B science aircraft is fitted with remote-sensing instruments to measure a number of variables within and near clouds, including those related to precipitation and cloud droplets as well as aerosol size and composition.

To verify those data, a Stratton Park Engineering Company (SPEC) Inc. Learjet, fitted with *in situ* instrumentation, flew in and around the same clouds at nearly the same time as the P-3B aircraft. The Learjet surveyed the atmospheric conditions above the clouds. Meanwhile, out in the Pacific Ocean, the research vessel *Sally Ride*, funded by the Office of Naval Research Propagation of InterSeasonal Tropical OscillatioNs (PISTON) project and operated by the Scripps Institution of Oceanography, University of California, San Diego, provided nearly continuous radar and lidar observations as well as measurements of energy fluxes from the ocean surface and profiles of temperature, moisture and pressure from radiosondes. CAMP^{2}Ex and PISTON are complementary in their goals. CAMP^{2}Ex focuses on fundamental aerosol and cloud physics and remote sensing whereas PISTON focuses on air–sea interaction and the way in which weather develops on continental and intercontinental scales.

"The synergy between air and shipborne observations is key," said **Derek Posselt** [NASA/Jet Propulsion Laboratory]. "The ship's radars will tell us how clouds are evolving in time, while the aircraft will give us detailed measurements of the cloud interior and environment."

In addition to the intricate aerosol and cloud processes, the Southeast Asian monsoon environment hosts some of the most complex atmospheric phenomena on the planet. The monsoon environment is conducive to the formation of severe thunderstorms and organized convection storm systems, and it is also the birthplace of tropical cyclones in the western Pacific. The world's most intense super typhoons form just east of the Philippines and are an integral part of the regional weather and climate. "CAMP^{2}Ex is being conducted in the lion's den of tropical meteorology," Reid said, while noting that the Philippines is still recovering from Super Typhoon Haiyan in 2013, which reached a world record one minute of sustained 195 mph (315 km/hr) maximum wind speed before making landfall.

The region is of particular interest to weather and climate researchers because many studies have shown it to be highly vulnerable to climate change. For Philippine collaborators, the data from CAMP^{2}Ex will help to inform some of the biggest weather and climate questions in the Southeast Asia region.

"Rainfall is the most difficult variable to understand in our models, and it has an enormous impact on people here," said **Gemma Narisma** [Manila Observatory[1]—*Executive Director*] "Results from our Coordinated Regional Downscaling Experiment over Southeast Asia (CORDEX-SEA), for example, show that regional climate models do not do a good job simulating observed rainfall climatology."

Narisma, who is also an associate professor at the Ateneo de Manila University, noted that recent monsoonal activity in Metro Manila led to cancelled classes; before that, the region had been suffering from water shortage due to drought. "Our research is showing that more of these weather extremes, alternating dryness and heavy rainfall, are expected in the future," she said. "Improving our models for climate projections would allow us to better prepare for these swings in water availability and flooding."

Increased understanding of the mechanisms influencing those climactic changes is another important and hoped for offshoot of the campaign, said **James Simpas** [Ateneo de Manila University]. "The Southeast Asia region is experiencing significant industrial growth," he said. "We're emitting more and more particulates into the atmosphere, which means that a lot of the aerosol interactions we're studying now will be most likely further enhanced in the region in the future. The wealth of data from CAMP^{2}Ex will be analyzed for years to come and will shine more light on how our ways of life affect not only us but also the rest of the planet." ■

[1] The Manila Observatory is a nonprofit Jesuit research institution focused on atmospheric and Earth science in Southeast Asia. To learn more, visit *http://www.observatory.ph*.

Summary of the 2019 Earth Science Technology Forum

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Conversation Starters

To provide attendees with opportunities to network, collaborate, and discuss future areas of research, ESTF included both a panel and poster session.

Amber Emory and **Jacqueline LeMoigne** [both from ESTO] led a panel session titled, *Integrating Software and Hardware for New Observing Strategies*, which prompted discussion on how software and hardware integration could improve Earth observing measurements. The panelists were **Gordon Farquharson** [Capella Space], **Christopher Ruf** [University of Michigan], and **Joel Johnson** [The Ohio State University].

Michael Little and **Parminder Ghuman** [both from ESTO] chaired a poster session highlighting new technology for observing Earth. From spacecraft autonomy to phenology, the posters offered a diverse array of technological accomplishments.

Conclusion

Attendees felt the conference was engaging and worthwhile. They valued the opportunity to learn about so many cutting-edge technologies and build relationships with potential future collaborators. The poster session was a particular hit, with attendees noting how much they enjoyed interacting with presenters. Future attendees can expect a continuing emphasis on fostering discussion among researchers at ESTF 2020. Keep up to date with next year's ESTF as well as deadlines for project proposals online at *http://esto.nasa.gov*. ■

NASA Studies How Arctic Wildfires Change the World

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EDITOR'S NOTE: This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

Wildfires in the Arctic often burn far away from populated areas, but their impacts are felt around the globe. From field and laboratory work to airborne campaigns and satellites, NASA is studying why boreal forests and tundra fires have become more frequent and powerful and what that means for climate forecasting, ecosystems, and human health—see photo below.

Richard Chen [University of Southern California] walks through an area of standing dead black spruce trees in a burned area near Delta Junction, AK. He and his fellow Arctic-Boreal Vulnerability Experiment (ABoVE) researchers have dug sample pits throughout this area to measure the organic carbon content of the soil, to measure the depth-to-permafrost, and to make electronic measurements of soil moisture. **Photo credit**: NASA/Peter Griffith

"Fires are a natural part of the ecosystem, but what we're seeing is an accelerated fire cycle: we are getting more frequent and severe fires and larger burned areas," said **Liz Hoy** [NASA's Goddard Space Flight Center (GSFC)]. She works with NASA's Arctic-Boreal Vulnerability Experiment (ABoVE), a comprehensive field campaign that probes the resilience of Arctic and boreal ecosystems and societies to environmental change.[1]

Arctic wildfires differ from mid-latitude fires, such as those in California and Idaho. For one, fires in the lower 48 are often set by humans and are put out as fast as possible, since they are a risk to life and property. In the boreal forest and tundra, wildfires are mostly ignited by lightning strikes and are usually left to burn unless they threaten important infrastructures or human settlements. As a result, they often grow large and consume hundreds of thousands of acres of vegetation—see **Figure** for example.

[1] To view an overview of NASA's research in the Arctic, including ABoVE, visit *https://svs.gsfc.nasa.gov/13281*. To learn more about ABoVE, visit *https://above.nasa.gov*.

Figure. In 2014, megafires in Canada's Northwest Territories scorched more than 7 million acres of forest, releasing half as much carbon back into the atmosphere as all the plants and trees in Canada typically absorb in an entire year. **Image credit**: NASA/Peter Griffith

Also, unlike lower-latitude wildfires, most of the carbon emissions from Arctic fires come from burned organic soil rather than burned trees and shrubs.

"Arctic and boreal regions have very thick soils with a lot of organic material—see example in the photo below—because the soil is frozen or otherwise temperature-limited as well as nutrient-poor, its contents don't decompose much," Hoy said.

Researchers dig out and measure a block of soil in Saskatchewan, Canada, during a field expedition for NASA's ABoVE campaign. Soils in the Arctic and boreal regions have very thick organic mats that release large quantities of carbon to the atmosphere when a wildfire burns them. **Photo credit**: Sander Veraverbeke

The thick, carbon-rich, top soil layer of boreal forests and tundra acts as insulation for the *permafrost*, the perpetually frozen layer of ground underneath the surface organic mat.

"When you burn the soil on top it's as if you had a cooler and you opened the lid: the permafrost underneath thaws and you're allowing the soil to decompose and decay, so you're releasing even more carbon into the atmosphere," Hoy said.

A recent ABoVE study found that a single fire season in Canada emitted so much carbon into the atmosphere that it offset half of all the carbon removed from the atmosphere through annual tree growth across all of Canada's vast forests. So not only are wildfires in the Arctic impacted by global warming, which is leading to warmer and drier summers that create dry, tinder-box conditions—they are also in turn contributing to more climate change.

"I sometimes hear 'there aren't that many people up there in the Arctic, so why can't we just let it burn, why does it matter?'" Hoy said. "But what happens in the Arctic doesn't stay in the Arctic—there are global connections to the changes taking place there."

Changing Landscapes

The fire-driven thawing of permafrost causes land subsidence and soil collapse, creating a honeycombed landscape. In some places, new lakes form. In others, the resulting hollowed topography, known as *thermokarst*, dries up the landscape.

"Whether the fire-disturbed area will recover or go forward toward subsidence depends on how much ground ice is underlaying in the ground," said **Go Iwahana** [University of Alaska, Fairbanks (UAF)], who works with ABoVE. "Other factors at play are how severely the fire wounds the surface organic layer and the weather the burned area experiences after the fire."

Beyond altering landscapes that had been unperturbed for thousands of years, the disappearance of permafrost also means the irreparable loss of a historic record.

"As with ice cores in Antarctica and Greenland, we look at changes in water isotopes, gas content, and the ice structure of permafrost to understand what happened in the past," Iwahana said. "Modelers and fire specialists are predicting an increased number of boreal and tundra fires in the future—this will enhance the thawing of permafrost, and so the *paleoinformation* contained in the permafrost will be lost."

Changes to hydrological processes, together with how fire modifies the distribution of plant species, ultimately alter local ecosystems.

"After an intense fire, we can see changes in the overall vegetation composition of the land," Hoy said. "It's going to change the mammal species that are able to live there and how people can use the land, for example, for hunting."

Caribou and moose are the two main game species in Alaska. Each reacts very differently to burned landscapes. During the first decades after a large fire, moose herds move in to the area in pursuit of the young vegetation that grows back. But caribou, whose diets are very dependent on slow-growing surface lichens that take a very long time to recover, are harmed by fires.

"One of the major concerns in terms of wildlife management is that fires might restrict the range of the caribou," said **Alison York**, [UAF—*Coordinator of the Alaska Fire Science Consortium*].

Impacts on Health

Wildfires release large amounts of particulate matter, which are harmful to the respiratory and cardiovascular systems and can travel far and wide by winds.

"We hear a lot about the impacts of fires on health, but all those studies come from research coming from a single, generally short fire event," said **Tatiana Loboda** [University of Maryland, College Park]. "In the boreal forest region, fires are very common, very large, and they produce a lot of smoke. Even people who don't live nearby are exposed for a substantial period of time year after year."

Loboda recently launched a project through ABoVE to study how exposure to particulates from forest fires is impacting the health of people in Alaska, a state that has issued over 30 air quality advisories during this year's fire season alone. Though Loboda's study is limited to Alaska, wildfires impact public health around the planet.

"Fires happen during the warm months, when people spend a lot of time outdoors—especially indigenous people doing subsistence activities like fishing and hunting," said Loboda, who plans on comparing the exposure of native communities to wildfires with health outcomes. "They lack any kind of protection they would get by being indoors with the [air conditioner] on and closing their windows."

For her study, Loboda will use hospitalization records from Alaska's Department of Public Health to analyze how many people get ill during the fire season. She'll also analyze NASA satellite data that, combined with computer models, will allow her to create a detailed record of burning at the daily scale, as well as thorough inventories of fuel types—the kind of greenery that burns combined with the intensity of the fire determines how much particulates are created.

"In the last 20 years we've had the three largest fire seasons on record for Alaska and that's happening at the same time that the population is growing," Loboda said. "The more people are spread out, the more likelihood someone is going to be affected somewhere in any given year." ■

in the news

An Inside Look at Hurricane Dorian from a Mini Satellite

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EDITOR'S NOTE: This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

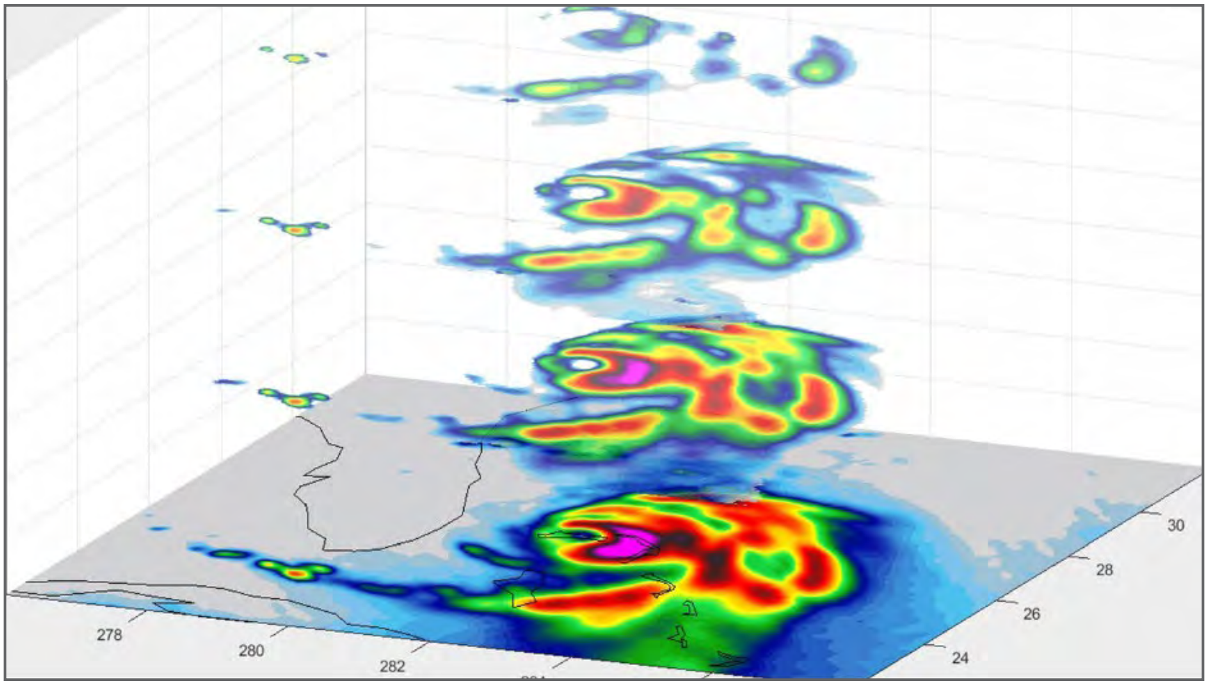

Figure. TEMPEST-D acquired this image of Hurricane Dorian off the Florida coast at 2 AM EDT on September 3, 2019, as it began to move toward the Southeast U.S. coast. The layers in the animation reveal slices of the hurricane from four depths, taken at different radio wavelengths. The vertical view of Dorian highlights where the storm is strongest in the atmosphere. For an animation of this image visit *https://photojournal.jpl.nasa.gov/archive/PIA23431.gif.* The colors in the animation show the heavy rainfall and moisture inside the storm. The least-intense areas of rainfall are shown in green, while the most intense are yellow, red and pink. **Image credits**: NASA/Jet Propulsion Laboratory and U.S. Naval Research Laboratory Marine Meteorology Division, Monterey (NRL-MRY)

NASA satellites provided many views of Hurricane Dorian, the first major hurricane of the 2019 Atlantic Hurricane Season, as it tracked across the Atlantic. The storm reached Category 5 intensity—with winds reaching as high as 185 mph (~298 km/h)—when it made landfall at Elbow Cay in the Bahamas on September 1, and later that same day at Grand Bahama. It then became nearly stationary for about a day unleashing devastating impacts on the Bahamas, before tracking westward, fluctuating in strength as it moved along the Southeast U.S. coast. The storm made an eventual U.S. landfall at Cape Hatteras, NC, as a Category 1 storm on September 6, before heading back out into the Atlantic.

One of the more interesting images obtained came from a NASA weather satellite that's the size of a cereal box. The Temporal Experiment for Storms and Tropical Systems Demonstration (TEMPEST-D) reveals rain bands in four layers of the storm as Hurricane Dorian approaches Florida on September 3, 2019—see **Figure**. The multiple vertical layers show where the strongest convective "storms" within the hurricane are pushing high into the atmosphere, with pink, red and yellow corresponding to the areas of heaviest rainfall.

Known as a CubeSat, TEMPEST-D uses a miniaturized version of a microwave radiometer—a radio wave instrument used to measure rain and moisture within the clouds. If TEMPEST-D can successfully track storms like Dorian, the technology demonstration could someday lead to a train of small satellites that work together to track storms around the world. CubeSats are much less expensive to produce than traditional satellites; in multiples they could improve our global storm coverage and forecasting data. ■

NASA Earth Science in the News

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EDITOR'S NOTE: This column is intended to provide a sampling of NASA Earth Science topics reported by online news sources during the past few months. Please note that editorial statements, opinions, or conclusions do not necessarily reflect the positions of NASA. There may be some slight editing in places primarily to match the style used in *The Earth Observer*.

California Hit with Biggest Wildfire of 2019 as NASA Warns on Climate, September 14, *bloomberg.com*. California's biggest wildfire of the year has already burned more than 50,000 acres of timber and grass as NASA scientists say climate change is making such blazes more likely and harder to stop. It's a sobering scenario for the U.S. state with the highest wildfire risk, where land damaged or destroyed by fire has expanded fivefold over the last four decades. Almost a half-million homes worth an estimated $268 billion are threatened, according to the online real-estate database company Zillow. "We're living in a warming and a drier world, and with climate change we're going to continue to see conditions that make fires more likely," said **Doug Morton** [NASA's Goddard Space Flight Center (GSFC)—*Chief of the Biospheric Sciences Laboratory*]. "They'll be definitely harder to suppress."

Al Roker Is in Greenland on a NASA Mission to Study Melting Glaciers for *Climate in Crisis* Series, September 12, *people.com*. Al Roker has trekked to the Arctic yet again—this time for a NASA mission in Greenland to study the effects of climate change on the rapidly melting glaciers and how sea levels are rising as a result. Months after traveling to Alaska to study the effects of climate change on the northernmost part of the U.S., in August the longtime television weather anchor flew with NASA scientists on their first-ever Oceans Melting Greenland (OMG) mission to study just how fast the warming ocean is melting the region's massive ice sheets. To watch the NBC News *Climate in Crisis* series, visit *https://www.nbcnews.com/now/video/nbc-news-now-climate-in-crisis-with-al-roker-69358149853.*

***Hurricane Dorian: NASA Mini-Satellite Reveals "What's Under the Hood,"** September 6, *orlandosentinel.com*. A tiny NASA satellite gave scientists a big data reveal on the inside of Hurricane Dorian and what makes it tick. TEMPEST-D[1] is a weather-observing satellite no bigger than a box of cereal—a relatively new class of platform known as a *CubeSat*. TEMPEST-D unveiled the hurricane's "engine" revealing phenomena at different depths of the hurricane and showing areas of heavy rainfall and moisture being pulled into the Dorian—see **Figure** in News Story on page 52. TEMPEST-D is an experiment that uses smaller, more cost-effective technology to understand cloud formation and tracking storms. Scientists hope that views from above the storm will provide valuable information regarding the life cycle of hurricanes.

NASA Satellites Confirm Amazon Rainforest Is Burning at a Record Rate, August 28, *space.com*. As raging fires continue to sweep through the Amazon rainforest in Brazil, NASA satellites are tracking the flames from above. Their view confirmed that this is the most active fire year in Brazil since 2010. Fire detections by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) on the Aqua satellite have been the highest since 2010 to date, with indications that 2019 may hit a record number of fires for several states in the Brazilian Amazon and departments in northern Bolivia—see **Figure 1** on the next page. (MODIS has been used to measure thermal anomalies all over the world since 2003.) The timing and location of MODIS' fire detections during this year's dry season in the rainforest are more consistent with land clearing than regional drought, **Douglas Morton** [GSFC—*Chief of the Biospheric Sciences Laboratory*] said in a statement by NASA.

NASA Helps California Get Ahead of Coastal Flooding, August 27, *spacedaily.com*. NASA, in cooperation with the U.S. Geological Survey, is helping emergency planners in Southern California get a more complete picture of the increasing risk of coastal flooding by looking at the highest of tides—called *king tides*. King tide is the informal term generally used to describe an exceptionally high tide, which most often occurs when the Moon and Sun are aligned and their gravitational pull on Earth is at its strongest. King tides can be just a few inches higher than normal, but when combined with other factors they can have damaging effects. To plan for higher waters, coastal engineers

[1] TEMPEST-D stands for Temporal Experiment for Storms and Tropical Systems – Demonstration. TEMPEST-D is sponsored by NASA's Earth System Science Pathfinder (ESSP) program and managed by the Earth Science Technology Office (ESTO). The goal of the TEMPEST-D mission is to validate the performance of a CubeSat microwave radiometer designed to study precipitation events on a global scale.

Figure 1. This map shows active fire detections in Brazil as observed by MODIS (on NASA's Terra and Aqua platforms), August 15-22, 2019. The locations of the fires, shown in orange, have been overlaid on nighttime imagery acquired by VIIRS. In this view, cities and towns appear white; forested areas appear black; and the vast tropical savannas and woodland regions (known in Brazil as the Cerrado) appear gray. Reminder for Print readers: The color version of the newsletter is available online. Visit *https://eospso.nasa.gov/earth-observer-archive/*, then click on "September–October 2019". **Credit:** NASA's Earth Observatory

in California use results from a USGS-based flood-simulation model for Southern California called the Coastal Storm Modeling System (CoSMoS). This online tool simulates flooding potential from sea-level rise and coastal storms along the central and southern California coastline. Until recently, CoSMoS got much of its sea-level data from tidal gauges scattered along the California coastline. To fill the gaps between the gauges, CoSMoS' developers at the USGS and NASA are adding data from NASA's satellite and airborne missions.

Images from a NASA Satellite Show the Quickly Increasing Levels of Carbon Monoxide in the Atmosphere from the Amazon Fires, August 23, *businessinsider.com*. Data from a NASA satellite have provided visualizations of increased carbon monoxide (CO) levels in the atmosphere due to the wildfires that continue to rage in the Amazon rainforest—see **Figure 2.** NASA collected new data from the Atmospheric Infrared Sounder (AIRS) instrument on its Aqua platform, measuring levels of CO at an altitude of 18,000 ft (5500 m) August 8-22, 2019, according to a press release. As an air pollutant that can travel long distances and stay in the atmosphere for about a month, CO plays a significant role in climate change. While the AIRS evaluated CO at a relatively high altitude and has little effect on the air we breathe as of right now, "strong winds can carry it downward to where it can significantly impact air quality," according to the press release. Concern for the world's largest rainforest arose as a record number of wildfires blazed through the Amazon this year (see previous entry)— a total of 72,843 incidents, according to Brazil's National Institute for Space Research (INPE). Nearly all fires in the Amazon are started by humans.

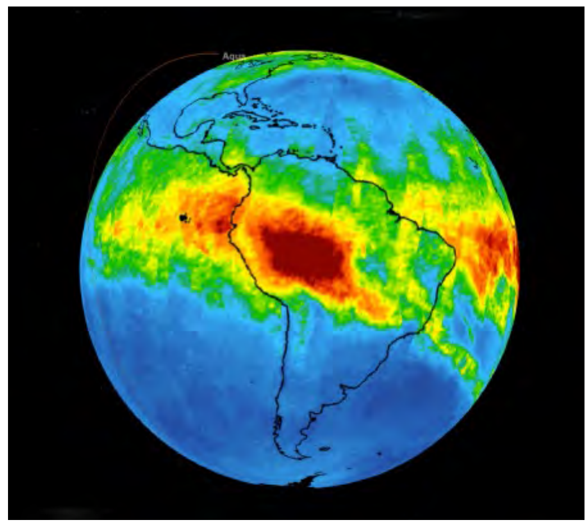

Figure 2. This image shows carbon monoxide associated with fires from the Amazon region in Brazil from August 8-22, 2019. Made with data collected from the Atmospheric Infrared Sounder (AIRS) on NASA's Aqua satellite, the image is made by averaging three days of measurements. **Image credit:** NASA/JPL

*For more information, see News story in this issue.

*Interested in getting your research out to the general public, educators, and the scientific community? Please contact **Samson Reiny** on NASA's Earth Science News Team at samson.k.reiny@nasa.gov and let him know of upcoming journal articles, new satellite images, or conference presentations that you think would be of interest to the readership of **The Earth Observer**.*

Earth Science Meeting and Workshop Calendar

NASA Community

October 29–31, 2019
CERES Science Team Meeting, Berkeley, CA
https://ceres.larc.nasa.gov/science-team-meetings2.php

November 18–22, 2019
MODIS–VIIRS Science Team Meeting, College Park, MD
https://modis.gsfc.nasa.gov/sci_team/meetings

January 27–31, 2020
2020 Sun-Climate Symposium, Tucson, AZ
http://lasp.colorado.edu/home/sorce/news-events/meetings/2020-scs

May 11–14, 2020
ABoVE Science Team Meeting, Fairbanks, AK
https://above.nasa.gov/index.html

Global Science Community

December 9–13, 2019
AGU Fall Meeting, San Francisco, CA
https://events.jspargo.com/AGU19/Public/enter.aspx

January 12–16, 2020
American Meteorological Society 100th Annual Meeting, Boston, MA
https://annual.ametsoc.org/2020

February 16–21, 2020
Ocean Sciences Meeting, San Diego, CA
https://www.agu.org/Ocean-Sciences-Meeting

April 25–26, 2020
USA Science and Engineering Festival, Washington, DC
https://usasciencefestival.org/2020-expo

May 3–8, 2020
EGU General Assembly 2020, Vienna, Austria
https://www.egu2020.eu

May 24–28, 2020
JpGU-AGU Joint Meeting, Chiba, Japan
http://www.jpgu.org/meeting_e2020

June 24–July 4, 2020
Asia Oceania Geosciences Society, Hongcheon, South Korea
http://www.asiaoceania.org/aogs2020/public.asp?page=home.html

List of Undefined Acronyms Used in Editorial and Table of Contents

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CNES	Centre National d'Études Spatiales [French Space Agency]
GSFC	NASA's Goddard Space Flight Center
LASP	Laboratory for Atmospheric and Space Research [University of Colorado]
NOAA	National Oceanic and Atmospheric Administration
SHADOZ	Southern Hemisphere ADditional OZonesondes
USFS	United States Forest Service
SRON	Stichting Ruimteonderzoek Nederland*

*This was the original name for SRON, but it's no longer used.

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Articles, contributions to the meeting calendar, and suggestions are welcomed. Contributions to the calendars should contain location, person to contact, telephone number, and e-mail address. Newsletter content is due on the weekday closest to the 1st of the month preceding the publication—e.g., December 1 for the January–February issue; February 1 for March–April, and so on.

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